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January 1996

Final Report

A Study of the Heavy Truck to Light Vehicle Accident Environment

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16. Abstract

Each year approximately 4,000 passenger car and light truck (hereafter referred to as light vehicle) occupants are killed in collisions with medium and heavy trucks (hereafter referred to as heavy truck). Another 120,000 are injured in those types of crashes. A majority (70%) of those collisions involve the front structure of the truck impacting the front, side, or rear of the other vehicle in the collision. Most of these crashes occur on roadways with relatively high posted speed limits (> 45 mph).

In the past, it has generally been assumed that this type of collision was unaddressable due to the large mass differential between the two vehicles involved, and the relatively high speeds. Recent studies have noted, however, that geometric mismatches between the collision partners, as well as the unusually stiff and rigid structure of the heavy truck contribute to the lethality of these collisions.

This report presents the results obtained to date from a pilot study involving the analysis of heavy truck-to-light vehicle accident data. A total of 43 serious (AIS>3) and non-serious accident cases involving the front of heavy trucks impacting the front or sides of a light vehicle were reviewed. The variables examined included vehicle damage, presence and amount of override, collision angles, principal direction of force (PDOF), intrusion, ΔV, occupant injury, source of injury, restraint use, etc. An assessment was also made after examining the above if lowering, softening, or changing the shape of the heavy truck front would have mitigated the injuries to light vehicle occupants.

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EXECUTIVE SUMMARY

Each year approximately 4,000 passenger car and light truck (hereafter referred to as light vehicle) occupants are killed in collisions with medium and heavy trucks (hereafter referred to as heavy truck). Another 120,000 are injured in those types of crashes. A majority (70%) of those collisions involve the front structure of the truck impacting the front, side, or rear of the other vehicle in the collision. Most of these crashes occur on roadways with relatively high posted speed limits (> 45 mph).

In the past, it has generally been assumed that this type of collision was unaddressable due to the large mass differential between the two vehicles, and the relatively high speeds involved. Recent studies have noted, however, that geometric mismatches between the collision partners, as well as the unusually stiff and rigid structure of the heavy truck contribute to the lethality of these collisions.

This report presents the results obtained to date from a pilot study involving the analysis of heavy truck-to-light vehicle accident data. This study is a part of an ongoing effort to assess the feasibility of utilizing heavy truck bumper designs that will result in survivable heavy truck-to-light vehicle collisions at approach velocities in the range of 40-60 mph (greater than 35 mph, the New Car Assessment Program (NCAP) test speed).

This report contains the following:

1. The results obtained to date from the analysis of heavy truck-to-light vehicle accident data obtained from the National Accident Sampling System (NASS) database for calendar years 1981-1987.

2 An analysis of the above results to determine the accident cases which could possibly have benefitted from the use of a modified heavy truck front end.

A total of 43 serious (AIS > 3) and non-serious accident cases were analyzed. These cases involved the front of a heavy truck impacting the front or sides of a light vehicle. Variables examined included: vehicle damage, presence and amount of override, collision angles, principal direction of force (PDOF), intrusion, ΔV, occupant injury, source of injury, and restraint use. An assessment was also made if lowering, softening, or changing the shape of the heavy truck front possibly would have mitigated the injuries to light vehicle occupants.

A total of 23 serious frontal collision cases were examined, of which 17 were judged as potentially benefiting from alterations to the front of the truck. The majority of these cases involved offset frontal collisions. Additional benefit may also be obtained in side impact cases where the region impacted is on the front or rear half of the light vehicle.

1.0 BACKGROUND

Each year approximately 4,000 passenger car and light truck (hereafter referred to as light vehicle) occupants are killed in collisions with medium and heavy trucks (hereafter referred to as heavy truck). Another 120,000 are injured in those types of crashes. A majority (70%) of those collisions involve the front structure of the truck impacting the front, side, or rear of the other vehicle in the collision.

In the past, it has generally been assumed that this type of collision was unaddressable due to the large mass differential between the two vehicles involved. Recent studies have noted, however, that geometric mismatches between the collision partners, as well as the unusually stiff and rigid structure of the heavy truck contribute to the lethality of these collisions.

2.0 OBJECTIVE

The objective of this report is to estimate the number of accident cases which could have benefitted from various alterations to the front end of heavy trucks.

3.0 ACCIDENT DATA ANALYSIS

A selection of NASS accident reports was reviewed. The accidents involved a heavy truck impacting a light vehicle. The Statistical Analysis System (SAS©) software was used to query the NASS database and hardcopy reports were obtained from the National Center for Statistics and Analysis (NCSA).

3.1 Selection of Accident Cases:

NASS accident data (unweighted) were retrieved for calendar years 1981-1987. The filters applied to the data included the following: all cases involving light vehicles (e.g., passenger cars, light trucks, vans, etc.) with gross vehicle weight (GVW) $<$ 10,000 lb_f, and heavy trucks with GVW $>$ 26,000 lb_f, occupants with known injuries ($1 \leq AIS \leq 6$) and unknown injury severity (AIS = 7), heavy truck impact direction in the 11, 12, and 1 o'clock positions and light vehicle impact in all directions.

3.2 Results to date

There were a total of 243 crashes which resulted in 346 injuries in the above mentioned 7 year period. Out of the 243 crashes, 49 were serious-fatal ($3 \leq AIS \leq 6$), 178 were non-serious ($1 \leq AIS \leq 2$), and 16 were cases with unknown injury severities.

Tables 3.1 and 3.2 show the distribution of heavy truck-to-light vehicle serious-fatal and non-serious crashes by region of impact respectively. Tables 3.3 and 3.4 show the distribution of heavy truck-to-light vehicle serious-fatal and non-serious accidents by the principal direction of force respectively. It should be noted that the clock directions are approximations and do not always correspond to the exact PDOF on vehicles.

Table 3.1 Distribution of 1981-87 Heavy Truck-to-Light Vehicle Serious Accident Cases (Unweighted) by Region of Impact on Both Vehicles

Truck Front Impacted

3 6%	22 45%	11 22.4%	1 2%	12 24.5%	49 100%
Unknown	Front	Right	Rear	Left	Total

Light Vehicle region Impacted(*)

Table 3.2 Distribution of 1981-87 Heavy Truck-to-Light Vehicle Non-Serious Accident Cases (Unweighted) by Region of Impact on Both Vehicles

Truck Front Impacted

28 15.7%	35 19.6%	29 16.3%	56 31.5%	30 16.8%	178 100%
Unknown	Front	Right	Rear	Left	Total

Light Vehicle region Impacted(*)

* Front Denotes 11, 12, and 1 o'clock directions
Right Denotes 2, 3, and 4 o'clock directions
Rear Denotes 5, 6, and 7 o'clock directions
Left Denotes 8, 9, and 10 o'clock directions

Table 3.3 Distribution of 1981-87 Heavy Truck-to-Light Vehicle Serious Accidents by Principal Direction of Force on Both Vehicles

			Heavy Truck PDOF (Clock angle)			
			11	12	1	Total
Light Vehicle PDOF (Clock angle)	Unknown		1	1	1	3
	1	Front	1	1		2
	2	Side	1	1		2
	3	Side		8		8
	4	Side		1		1
	5	Rear				
	6	Rear		1		1
	7	Rear				
	8	Side		1		1
	9	Side	1	4	1	6
	10	Side		2	3	5
	11	Front		4	3	7
	12	Front	1	12		13
					Total	49

Total Light vehicle Side = 23
Rear = 1
Front = 22

Table 3.4 Distribution of 1981-86 Heavy Truck-to-Light Vehicle Non-Serious Accidents by Principal Direction of Force on Both Vehicles

			Heavy Truck PDOF (Clock angle)			
			11	12	1	Total
Light Vehicle PDOF (Clock angle)	Unknown		3	21	4	28
	1	Front	4	5		9
	2	Side	7	6		13
	3	Side	1	15		16
	4	Side				
	5	Rear	1	4	1	6
	6	Rear	1	40		41
	7	Rear		7	2	9
	8	Side		4	1	5
	9	Side		14	1	15
	10	Side		3	7	10
	11	Front		4	2	6
	12	Front	1	16	3	20
					Total	178

Total Light Vehicle Side = 59
Rear = 56
Front = 35

Hard-copy reports were reviewed for a total of 43 cases. After examining 12 cases (based on availability) involving heavy truck-to-light vehicle sides, it was decided to examine the cases involving heavy truck-to-light vehicle fronts. The side impact cases were considered to be less likely to be survivable at high speeds. A few non-serious (8) and all the serious front impact cases (23) in the years 1981-87 involving heavy truck and light vehicle fronts were examined. The heavy truck front and light vehicle front impacts are summarized in Table 4.1, and the side impact cases in Table 4.4.

The principal information obtained from these reports included a description of the accident, occupant injury, restraint use, and vehicle damage. The ΔV for the light vehicle was calculated from equations used in the CRASH3 damage algorithm (Appendix A) when the damage measurements of the vehicles were available. If the damage information was missing, the ΔV of the light vehicle was calculated assuming conservation of momentum, and initial velocities of the truck and the light vehicle to be the posted speed limits. It should be noted that the ΔV calculated this way is conservative, as the effects due to braking, avoidance maneuvers, etc. are ignored in the simple momentum balance calculations. A revised estimate for ΔV was calculated after conducting 6 tests, to correct for these effects. A correction factor of 1.6 was obtained to account for the energy absorbed by the truck. The derivation of this correction factor is explained in Appendix A. Based on a review of the crash sequence and photographic evidence, a technical judgement was made on the possible benefits which could be obtained from modifying the truck front end. These conclusions are summarized in Tables 4.1 and 4.4. In addition, the copies of the accident diagram and photographs of the damaged vehicles are also included.

4.0 NASS HARDCOPY ANALYSIS

The essential findings and conclusions from the NASS hardcopy analysis are described in the following sections. Each case consists of a case description, collision diagram, and vehicle photographs. The front impact cases are described in section 6.1, and side impacts in section 6.2. The results are discussed in section 3.2.

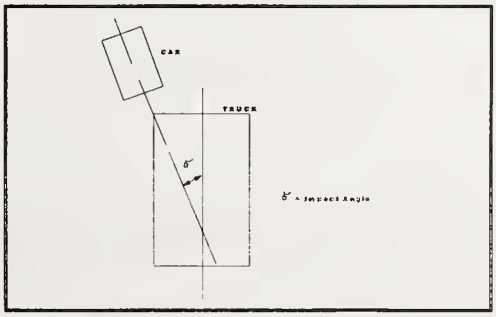
The NASS cases involving truck and car fronts are summarized in Table 4.1. The national weighting factor is used to estimate the total number of accidents, fatalities and addressable cases. A similar analysis is carried out for side impacts (cases involving truck fronts and car sides) and is summarized in Table 4.4. From the review of the cases it was decided to address the front impact cases first. Side impacts involving trucks tend to be very severe, with extensive intrusion and violation of the passenger compartment integrity.

The different columns in Table 4.1 are described below:

Column 1: Year: This is the year the accident occurred.

Column 2: PSU: This is the Primary Sampling Unit in the NASS database.

Column 3: Case: This is the Case Number in the NASS database. The combination of



1.1 **Figure 4.1** Impact Angle

Year, PSU, and Case uniquely identify the accident in the NASS database.

Column 4: NATWGT:This is the national weighting factor for the accident

Column 5: Full/Offset: Indicates if the impact involved the entire or part of the car-width.

Column 6: % car engaged: The extent of the car-front directly engaged by the truck-front.

Column 7: Impact angle: This describes the orientation of the two vehicles' center lines at the point of impact (see Fig. 4.1)

Column 8: Serious: This indicates if the accident is considered serious (MAIS $\geq$ 3)

Column 9: MAIS: This is the maximum AIS injury level of occupants in the car.

Column 10: Intrusion: This is the amount of intrusion in the car.

Column 11: Override: This indicates if the truck bumper overrode the car bumper

Column 12: Fatalities: This is the number of fatalities in the car.

Column 13: ΔV: This is the velocity change of the car in the approach phase of the impact. The values of ΔV are calculated using the CRASH3 damage algorithm (see Appendix A) whenever possible. The values calculated by using the conservation of momentum using posted speed limits are marked by the symbol #.

Column 14: Geometric factor: For angled impacts, this indicates if the car would tend to rotate into the path of the truck (see figure 4.2). A value of 1 indicates rotation into the trucks path, while a value of 0 indicates rotation away from the truck's path.

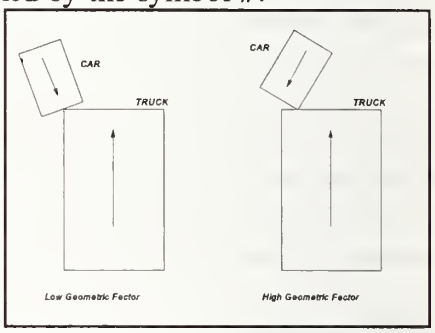


Figure 4.2 Geometric Factor

Column 15: Override Factor: This indicates the relative amount of override of the car bumper by the truck (see figure 4.3).

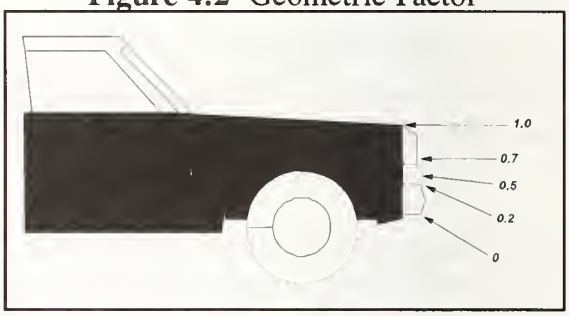


Figure 4.3 Override Factor

Column 17: Addressable: This indicates a judgement as to whether or not the car occupants would have significantly benefited by changing the truck front.

Column 18: Lowering: This indicates if lowering the truck front would be beneficial.

Column 19: Softening: This indicates if softening the truck front would be beneficial.

Column 18: Deflecting: This indicates if contouring the truck front would be beneficial. The cases where the deflecting bumper may cause increased severity are indicated by **.

In addition to the above factors, two other factors are calculated as follows:

$$(EngagementFactor1)=1-\left(\frac{\%engaged}{100}\right) \quad \textbf{(4.1)}$$

$$(EngagementFactor2)=4\times\left(\frac{\%engaged}{100}\right)\times\left\{1-\left(\frac{\%engaged}{100}\right)\right\} \quad \textbf{(4.2)}$$

These factors are chosen to reflect the two possible effects of the amount of offset present in impacts. ENGAGEMENT FACTOR 1 varies linearly with the offset, having a minimum value of 0 when the entire car front is engaged. On the other hand, ENGAGEMENT FACTOR 2 is a quadratic with the maximum value of 1 at 50 % engagement.

4.1 National Estimates:

The NASS database was searched for all serious (MAIS ≥ 3) and non-serious accidents involving truck fronts and car fronts in the years 1981-1987. The results are summarized in Tables 4.2 and 4.3 respectively. There were 1,792 serious truck-car impacts involving the front of the truck, resulting in 1,058 fatalities in this period. Based on hardcopy analysis of the available cases, the national estimates indicate that about 76 % of the serious front impact accidents can be potentially addressed by the combination of lowering, softening, or contouring the truck bumpers. It is determined that a deflecting bumper design may be of some help in 46 % of the cases. In certain cases, however, changing the shape of the truck bumper might result in presenting a narrower and more aggressive profile to the car. These cases, typically full frontal head-on impacts, are marked by ** in Table 4.1.

The national weighting factor NATWGT in the NASS database was used to find national estimates of the number of accidents as well as the number of fatalities in these accidents as :

$$Q=\sum_i (f_i \times w_i)$$

where f_i is 1 for calculating estimates of the number of accidents, and is the number of fatalities in each accident for calculating the national fatality estimates, and w_i is the national weighting factor for each case. The error is calculated as

$$E=\frac{\sqrt{\sum_i f_i \times w_i^2}}{\sum_i f_i \times w_i}$$

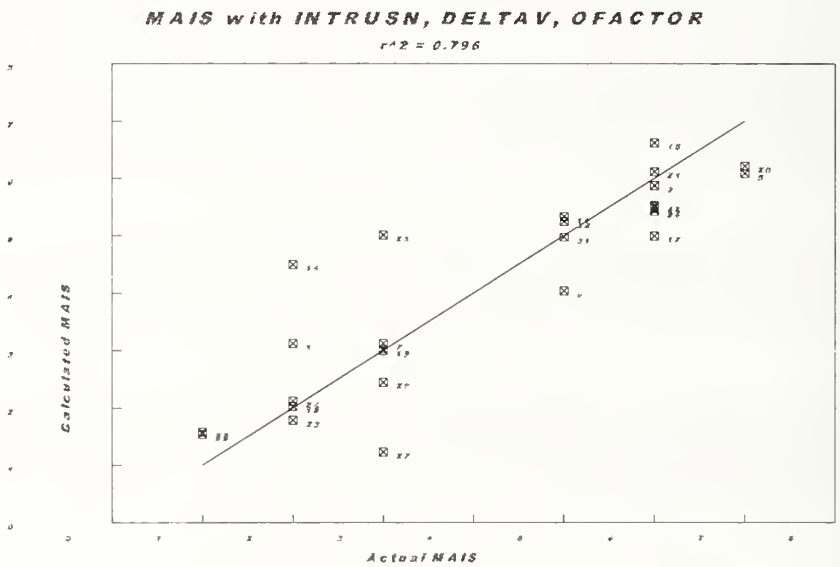
It should be noted that the determination of addressability of cases was based on NASS hardcopy analysis (examination of accident data-forms, injuries, collision diagrams, estimated accident speeds, and collision geometries).

4.2 Regression and Correlation Analysis

Statistical analysis were conducted on the front impact data to determine the most significant factors affecting accident severity. MAIS and the number of fatalities in crash were considered to be the primary indicators of accident severity. The results are presented in Appendix B. It can be seen that intrusion, override factor, and ΔV are the three most significant factors (with $R^2 = 0.8$) in determining the MAIS. The quality of fit is indicated in Fig 4.4 with the actual and calculated values of MAIS plotted on the X and Y axes respectively. Similarly, the number of fatalities is related to intrusion, override factor, and engagement factor2 ($R^2 = 0.62$). It should be noted that the value of intrusion is not well determined in the NASS hardcopies, with most cases being marked as "intrusion > 12 inches". A value of 12 inches has been assigned as the intrusion in these cases. Also, the values of MAIS and the number of fatalities are discrete integer values

and fall in a narrow range. Thus, the results of the regression analysis should be interpreted with some care.

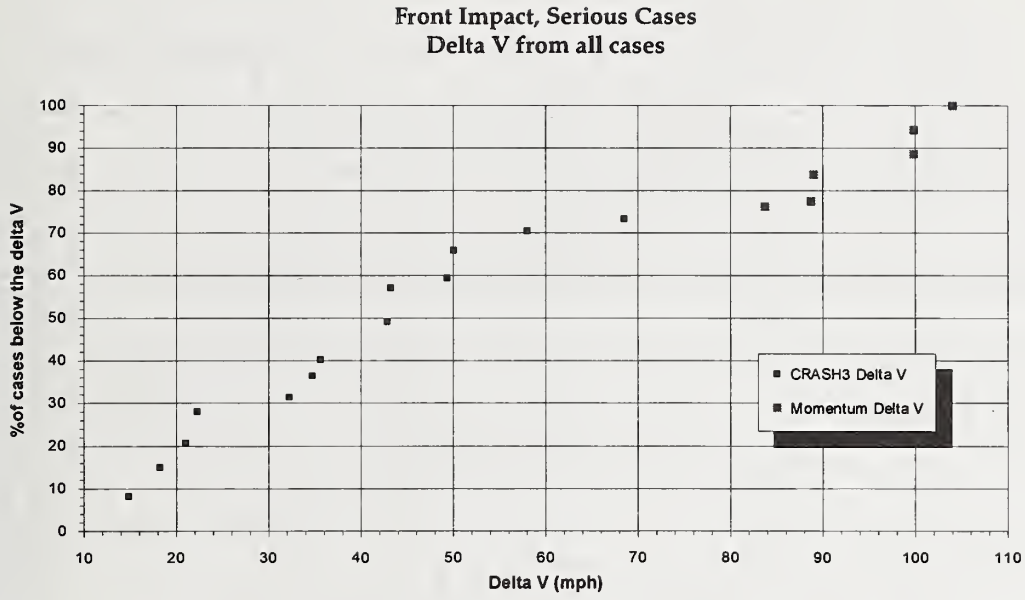
Regression analysis was also carried out on the subset of cases where ΔV was calculated using the CRASH3 damage algorithm. The values of ΔV calculated assuming conservation of momentum are subject to uncertainties in the estimate of initial truck and car velocities. For these cases too, the values of intrusion and override factor result in $R^2 = 0.67$. The number of fatalities are related to intrusion, override factor, and engagement factor2 with $R^2 = 0.6$. The details of the regression analysis can be found in Appendix B.



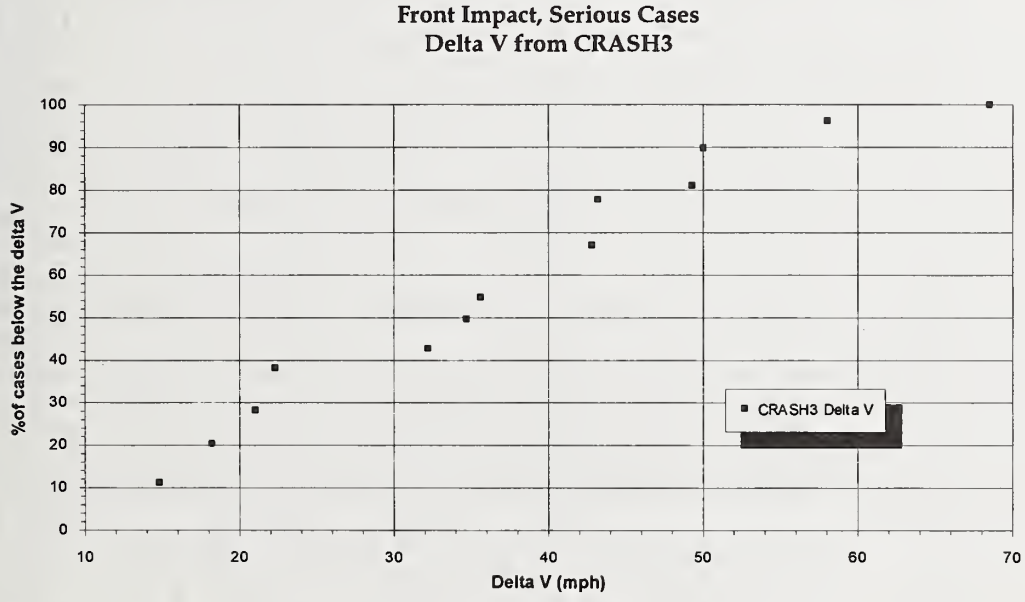
4.5 **Figure 4.4** Regression Of MAIS for all Front Impact cases

The distribution of ΔV of serious cases involving the heavy truck and light vehicle fronts was examined. The cumulative fraction of cases (national estimates) was plotted as a function of ΔV. The plot for all cases in Table 4.1 is shown in Fig. 4.5.

It should be noted that in cases where damage measurements were not available, ΔV was calculated assuming conservation of momentum, assuming initial velocities of the vehicles to be the posted speed-limits, and both vehicles attaining a common velocity. These assumptions will generally result in high values of ΔV, as the loss of speed of the vehicles involved due to braking, road/shoulder friction, driver intervention, etc. are ignored. Therefore, the results should be viewed as conservative. Speed distribution in cases where ΔV was calculated using the CRASH3 damage algorithm is plotted in Fig. 4.6. The values of ΔV in this plot are more likely to be representative of the actual speeds. However, this analysis will be biased toward lower ΔV as the more severe impacts (where CRASH3 algorithm could not be used) are excluded from the analysis.



4.5 **Figure 4.5** ΔV Distribution, Severe Front Impacts, All Cases



4.5 **Figure 4.6** ΔV Distribution, Severe Front Impacts, CRASH3 Analysis Cases

The above figures indicate that the ΔV in 50 % of the serious front impacts is below 40 mph, when all cases are considered (and the higher ΔV's are calculated using the less accurate conservation of momentum method). When cases reconstructed using the CRASH3 algorithm are considered, 70% of the cases have ΔV less than 40 mph (biased towards lower values as cases with very high severities are not considered).

Table 4.1 Summary of Truck Front Impact Cases: 1981-1987

Year	PSU	Case	NAT WGT	Full(F)/ Offset(O)	% car engaged	Impact Angle	Serious	MAIS	Intrusion (inch)	Override	Fatality in car	Car ΔV mph	Geometric Factor	Override Factor	Addressable	Lowering	Softening	Deflecting
81	28	12	797.3	O	50	10	N	2	0	Y	0	32.0#	0.3	0.7	Y	Y	Y	Y
81	53	214	205.8	O	50	0	N	1	0	N	0	N/A	0.5	0.5	Y	Y	N	Y
82	05	143	101.0	O	10	-5	Y	6	>12	N	1	89.0#	0.6	0.2	N			
82	54	116	107.3	O	60	-30	Y	5	>12	N	0	N/A	1.0	0.2	Y	N	Y	N**
82	53	227	48.2	F	100	10	Y	7	>12	Y	1	83.7#	0.2	0.4	N			
82	53	103	80.4	O	50	0	Y	7	>12	Y	1	N/A	0.4	0.3	N			
83	80	25	108.0	O	20	0	Y	3	>6	Y	0	18.2	0.5	0.4	Y	Y	Y	Y
83	53	102	60.3	O	40	-20	Y	6	>12	Y	1	35.6	0.7	0.7	Y	Y	Y	Y
83	30	12	132.1	O	50	-10	Y	5	>12	N	0	14.8	0.6	0.1	Y	N	Y	N**
83	53	200	144.7	O	50	25	Y	5	>12	N	1	42.8	0.0	0.5	Y	N	Y	Y
83	08	289	125.8	O	90	60	Y	3	>6	N	0	43.2	0.0	0.0	Y	N	Y	Y
83	29	168	158.9	O	50	0	N	2	0	N	0	28.0	0.2	0.5	Y	N	Y	Y
84	54	96	80.9	F	90	5	Y	3	2-6	Y	0	34.7	0.7	0.1	Y	Y	Y	N**
84	12	35	76.5	F	100	0	Y	6	>12	Y	1	99.8#	0.4	0.5	N			
84	82	19	58.3	O	40	-30	N	2	>12	N	0	28.0	0.4	0.2	Y	N	Y	N**
84	76	29	55.7	O	20	-70	N	2	0	N	0	50.7#	0.0	0.2	Y	N	Y	N**
85	11	133	103.6	F	100	5	Y	6	>12	N	2	50.0	0.4	0.2	N			
85	79	78	19.9	O	90	0	Y	6	>12	N	1	88.7#	0.7	0.0	N			N**
85	38	227	38.1	F	100	30	Y	6	>12	Y	1	49.3	0.5	0.5	Y	N	Y	N**
85	12	56	92.2	F	100	10	Y	7	>12	N	1	104.0#	0.0	0.2	Y	Y		Y
85	12	21	91.0	F	95	45	Y	6	>12	Y	1	99.8#	0.9	0.2	Y	Y		N**
85	11	275	45.0	O	100	30	Y	5	>12	N	1	68.5	0.0	0.1	Y	Y	Y	Y
85	29	105	102.5	O	30	-5	N	2	0	N	0	9.9	0.4	0.6	Y	Y	Y	N
85	59	110	104.8	F	100	0	N	2	0	Y	0	17.4	0.5	0.7	Y	Y	Y	N**
85	38	330	76.3	F	100	10	N	1	0	Y	0	30.6#	0.5	0.2	Y	Y	Y	Y
86	58	176	53.6	O	50	0	Y	6	>12	Y	1	32.2	0.6	0.7	Y	Y	Y	Y
86	61	46	117.1	O	40	60	Y	3	0	N	0	22.3	0.1	0.1	Y	N	Y	Y
86	33	38	73.7	F	90	30	Y	3	>12	N	0	58.0	0.3	0.1	Y	N	Y	Y
86	13	52	92.1	O	70	-20	Y	3	1	Y	0	21.0	0.8	0.7	Y	Y	Y	N**
86	59	189	66.6	O	20	0	N	1	0	N	0	6.6	0.4	0.5	Y	Y	Y	N
87	38	65		F	100	25	Y	5	>12	Y	2	34.2	0.3	0.4	Y	Y	Y	Y

* => Being simulated at TSC
\# => Using Conservation of Momentum using posted speed limits
** => May harm

Table 4.2 Summary of Truck Front Impacts: Serious Cases: 1981-1987

Total number of	Number of Hardcopies	National Estimates		Error %
		Number	% of Total	
Accidents	22	1792		23
Fatalities	16	1058		29
Addressable Cases	16	1362	76	27
Fatalities in addressable cases	9	525	41	42
Full Frontal Impacts	9	605	34	37
Offset Frontal Impacts	13	1187	66	30
Deflecting may help	10	820	46	35
Deflecting may harm	7	561	31	41

† National Estimates are for the years 1981-86

Table 4.3 Summary of Truck Front Impacts: All Cases: 1981-1987

Total number of	Number of Hardcopies	National Estimates		Error %
		Number	% of Total	
Accidents	31	3417		28
Fatalities	16	1058		29
Addressable Cases	25	2988	87	31
Fatalities in addressable cases	6	525	50	42
Full Frontal Impacts	11	785	23	33
Offset Frontal Impacts	20	2632	77	35
Deflecting may help	14	2058	60	43
Deflecting may harm	10	780	23	34

† National Estimates are for the years 1981-86

Table 4.4 Summary of Truck Side Impact Cases: 1981-1987

Year	PSU	Case	NATWGT	Serious	MAIS	Car Intrusion (inch)	Override Y/N	Fatality in car	Addressable Y/N	Lowering	Softening	Deflecting
81	30	15	461.2	N	1	>0	N	0	N			
82	54	108	151.4	N	1	0	N	0	N			
82	27	110	80.6	N	2	0	N	0	N			
82	30	224	95.2	N	1	0	Y	0	N			
82	84	36	159.1	N	2	>10	N	0	Y	N	Y	N
83	12	124	121.7	Y	2	>10	Y	0	Y	Y	Y	N
83	27	150	92.3	Y	3	>10	N	0	Y	N	Y	Y
84	55	262	116.0	Y	4	>6	Y	0	Y	Y	Y	N
84	12	50	147.4	Y	3	>6	N	0	Y	N	Y	N
84	55	189	110.3	Y	5	>12	Y	0	Y	Y	Y	N
84	54	102	102.8	Y	6	>12	Y	1	N			N
84	32	161	23.2	N	2	>6	Y	0	Y	Y	Y	N

5.0 RECOMMENDED RESEARCH PLAN

Based on the findings of the NASS hardcopy analysis, it is recommended that a series of full scale crash tests be conducted to examine the effectiveness of modifying the truck front ends. The possible modifications are: lowering the truck front (to reduce override of the car bumper), softening the truck front, and reshaping the truck front to deflect cars away from the truck.

The parameters of interest in truck-car front collisions are: car size and front geometry, collision geometry, truck bumper height, stiffness, geometry. The car size and geometry could be varied by considering two car models, compact and large. The truck bumper could be lowered, softened, or tapered. Additionally, the following impact modes are considered:

- FF - Front Full
- FO - Front Offset (with various amounts of offset)
- FOb - Front Oblique (car rotating away from truck)
- FSOb - Front Side Oblique (car rotating into the path of the truck)

Lowering of the truck bumper and designing it to deflect the oncoming light vehicle is expected to be the most significant factor in mitigating the aggressivity of the truck. The truck front will be simulated by using an actual truck frame, with attachments to allow lowering and using bumpers with different front profiles. The structure will allow the bumper to be lowered, softened (by attaching a honeycomb front end), and tapered (by attaching a modified bumper).

6.0 LISTING OF NASS HARDCOPIES

The following pages describe the NASS hardcopies.

FRONT IMPACTS

Year	PSU	Case	Page#
1981	28	12	15
1981	53	214	20
1982	05	143	25
1982	54	116	29
1982	53	227	33
1982	53	103	37
1983	80	25	41
1983	53	102	46
1983	30	12	50
1983	53	200	54
1983	08	289	58
1983	29	168	62
1984	54	96	66
1984	12	35	71
1984	82	19	75
1984	76	29	79
1985	11	133	83
1985	79	78	88
1985	38	227	92
1985	12	56	96
1985	12	21	100
1985	11	275	104
1985	29	105	108
1985	59	110	113
1985	38	330	118
1986	58	176	122
1986	61	46	127
1986	33	38	131
1986	13	52	135
1986	59	189	139
1987	38	65	144

SIDE IMPACTS

Year	PSU	Case	Page#
1981	30	15	149
1982	54	108	154
1982	30	224	161
1982	84	36	165
1983	12	124	169
1983	27	150	173
1984	55	262	177
1984	12	50	182
1984	55	189	186
1984	54	102	189
1984	32	161	194

YEAR: 1981
PSU: 28
CASENO: 12
NATWGT: 797.3

ACCIDENT DESCRIPTION:

Vehicle 1: '72 Ford Station Wagon, 1 occupant.

Vehicle 4: '72 Mack MB200 oil truck, GVW > 33,000 lb_f, 1 occupant

Impact Angle: 10 deg

Geometric Factor: 0.3

Override Factor: 0.7

On a two lane roadway (speed limit 35 mph.), vehicle 1 was travelling south and vehicle 4 was stationary on the northbound lane. Vehicle 2 (not described), cut off vehicle 1 , impacted it, and forced vehicle 1 to impact vehicle 4 in a frontal offset mode. Vehicle 1 underrode vehicle 4. Vehicle 2 impacted vehicle 3 (not described).

OCCUPANTS:

Vehicle 1: Driver: unrestrained.

Vehicle 4: Driver: no information available.

DAMAGE:

Vehicle 1:
Location: Front
Direction of force: 12 clock direction
Deformation: The left front half of vehicle 1 sustained damage. The fender was pushed back approx. 20 inches. The damage occurred above the bumper level.
Intrusion: None
Ejection: None
Contact locations: The driver contacted the windshield, steering wheel, and left knee panel.
% Engaged: 50 % of front

Vehicle 4:
Location: Front
Direction of force: 12 clock direction
Deformation: The left front side of the truck was damaged. The damage occurred mostly on the bumper.
Intrusion: No intrusion
Ejection: none
Contact locations: None
% Engaged: Unknown

ΔV:

Vehicle 1: 62 mph. (from momentum)

Vehicle 4: Not calculated

INJURIES:

Vehicle 1: Driver sustained bruises to the head (AIS 2) due to contact with windshield, mouth (AIS 1) due to contact with the steering wheel, and right knee (AIS 1) due to contact with the knee panel.

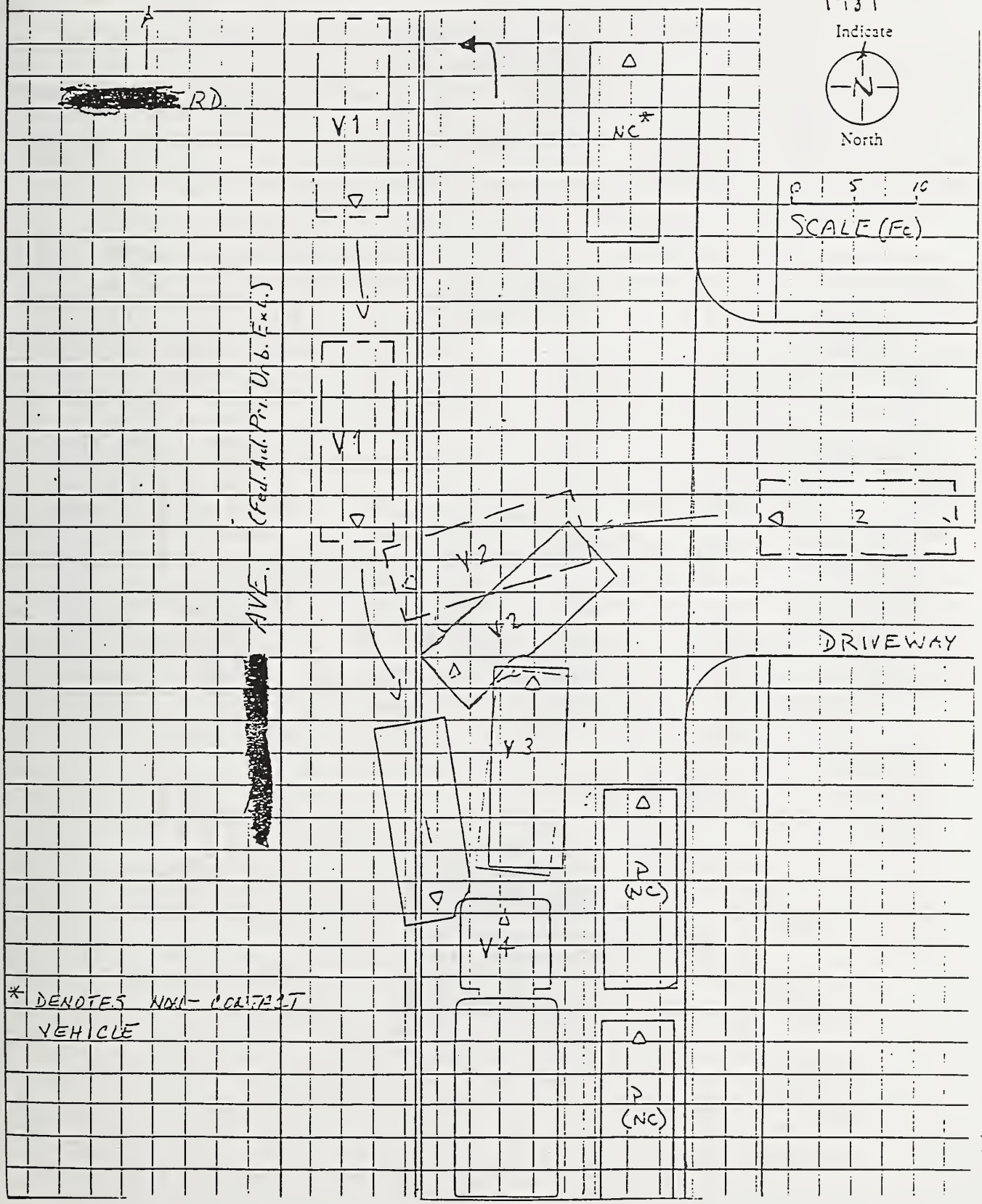
Vehicle 4: None

INJURY MITIGATION AND COMMENTS:

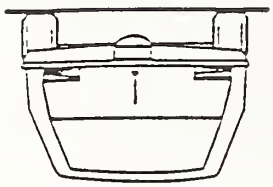
A modified truck front end would have been a benefit here. The bumper would have prevented vehicle 1 from underriding vehicle 4 and would have allowed both vehicles to mutually absorb the energy at impact. This would have diminished the amount of vehicle 1 crush and may have mitigated the driver injuries.

ACCIDENT COLLISION DIAGRAM

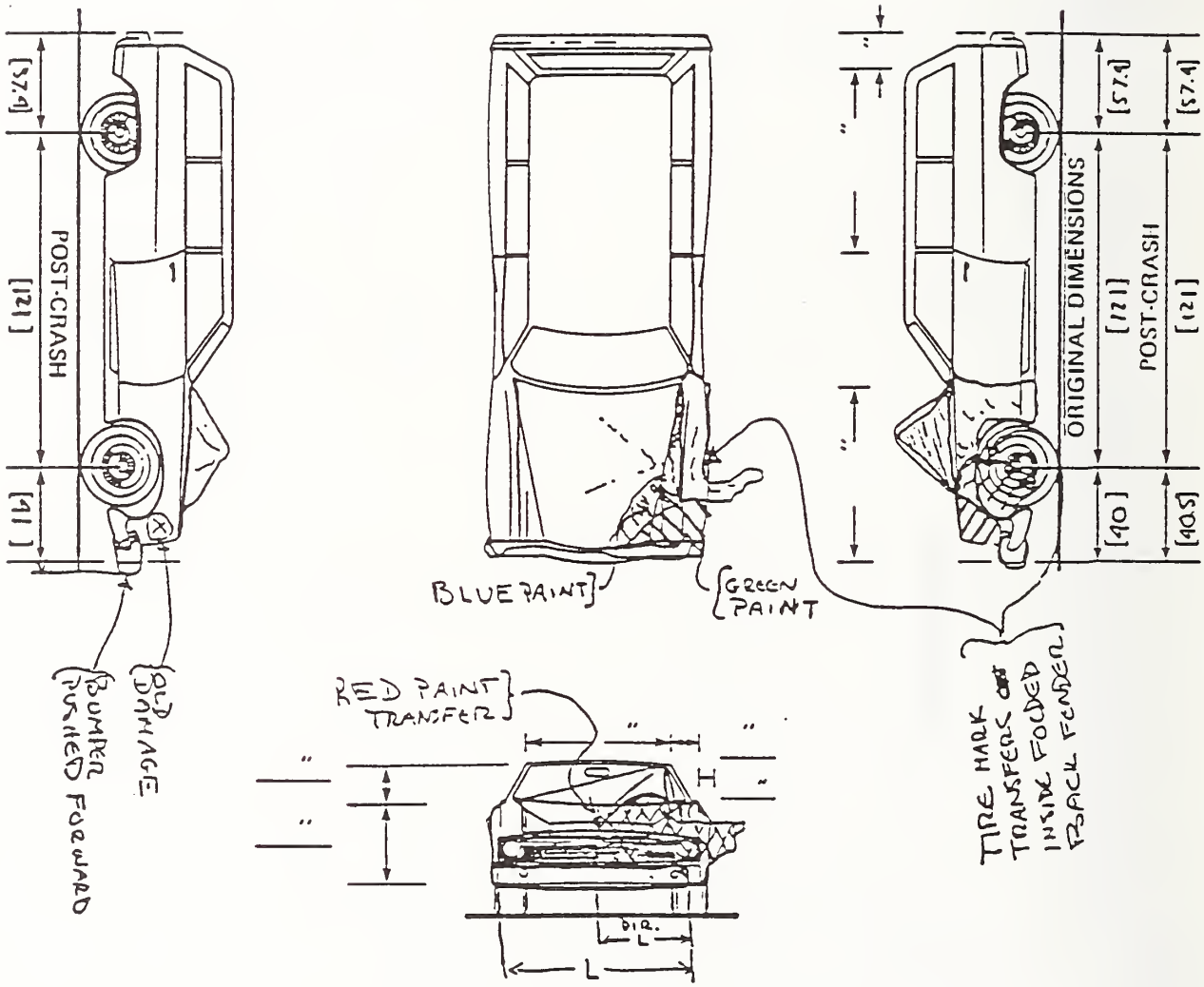
CASE # 12
PSU 28
1981



CASE #12
PSU 28
1981

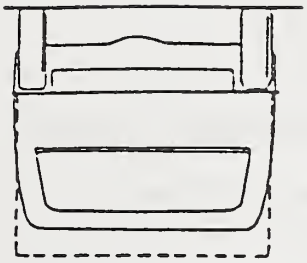


VEHICLE 1 - FORD RANCH WAGON



STRAIGHT TRUCKS
- Flat Bed/Platform
- Stake Bed
- Box or Van Body
- Tank
- With Single or Double Rear Axle

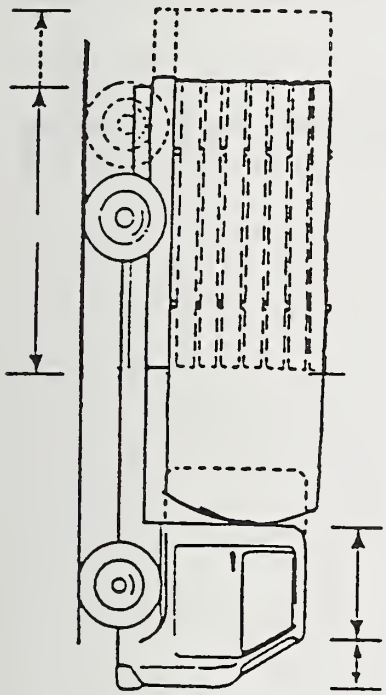
} CARGO CONFIGURATION

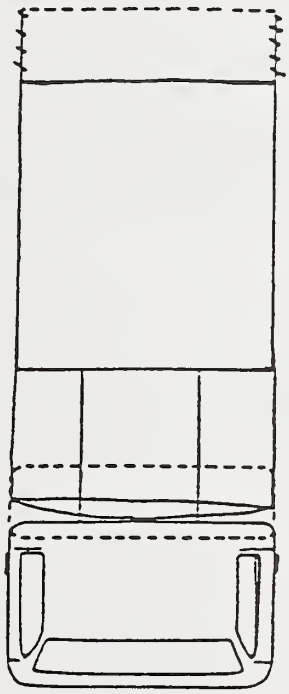


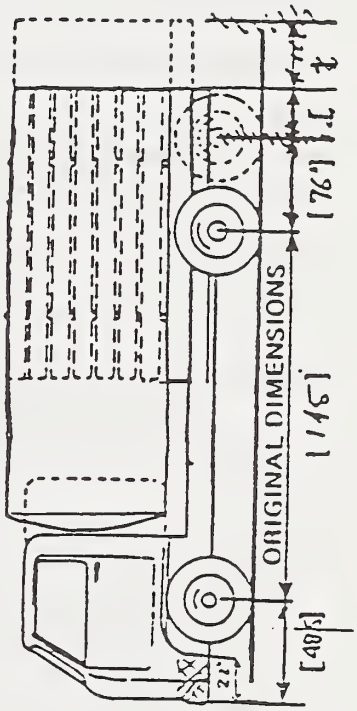
CASE #12
PSU 28
1981

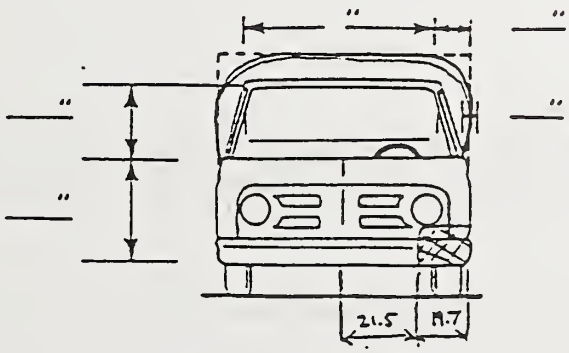
Number of Axles:
Total 2
Truck 2
Semi 1/1
Full 1/1

VEHICLE 4 72 MACK MB200 OIL TRUCK









YEAR: 1981
PSU: 53
CASENO: 214
NATWGT: 205.8

ACCIDENT DESCRIPTION:

Vehicle 1: '74 GMC 9500 w/trailer, GVW > 33,000 lb_f, 1 occupant.

Vehicle 2: '69 AMC Rambler 2 door sedan, 2 occupants.

Impact Angle: 0 deg

Geometric Factor: 0.5

Override Factor: 0.5

On a two lane roadway, vehicle 1 was travelling south while vehicle 2 was travelling north. Vehicle 1 veered left onto the northbound lane and struck vehicle 2. The left front corner of vehicle 1 struck the left front corner of vehicle 2. The photographs of the damaged vehicles were not available.

OCCUPANTS:

Vehicle 1: Driver: no information available.

Vehicle 2: Driver: no information available.
Passenger: no information available.

DAMAGE:

Vehicle 1:
Location: Front
Direction of force: 12 clock direction
Deformation: Minor damage to left front bumper and cracked left front fender.
Intrusion: None
Ejection: None
Contact locations: None
% Engaged: Unknown

Vehicle 2:
Location: Front
Direction of force: 12 clock direction
Deformation: Left front region sustained minor damage and the left side was sideswiped. There was approximately 4 inches of side crush and about 1 inch of frontal crush. The driver side door window was broken.
Intrusion: No intrusion
Ejection: none
Contact locations: Door side structure including hardware and armrest.
% Engaged: 10 %

ΔV:

Vehicle 1: Not calculated

Vehicle 2: Not calculated

INJURIES:

Vehicle 1: None

Vehicle 2: Driver sustained bruised ribs on the left part of the chest (AIS 1) due to contact with the door side structure.

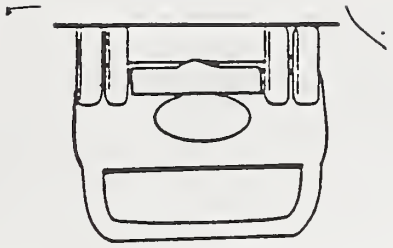
INJURY MITIGATION AND COMMENTS:

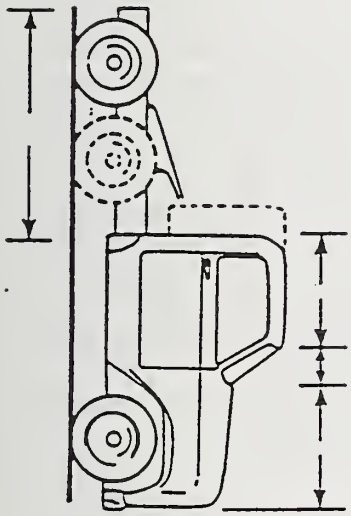
Based on the impact geometry and injury levels, a deflecting and energy absorbing truck front could have reduced the amount of vehicle damage and occupant injury.

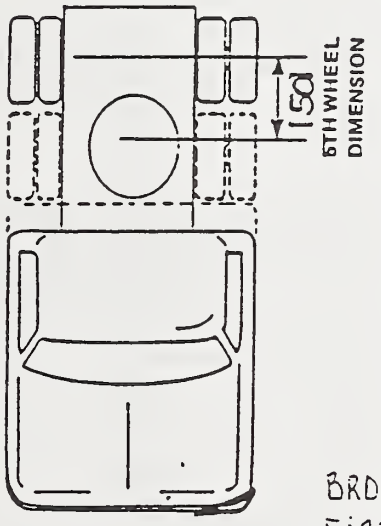
CASE # 214
PSU 53
1981

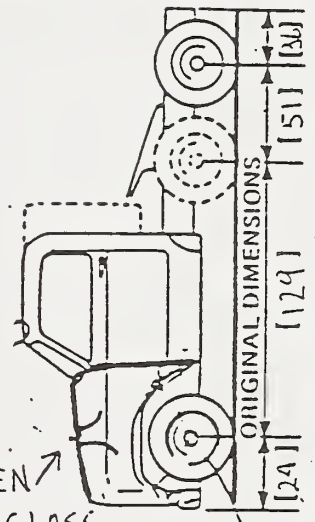
CASE = 214
PSU 53
1981

VEHICLE 1



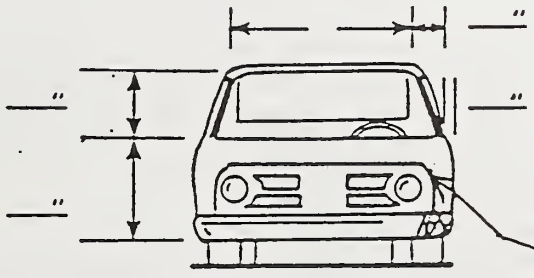






BROKEN FIBERGLASS

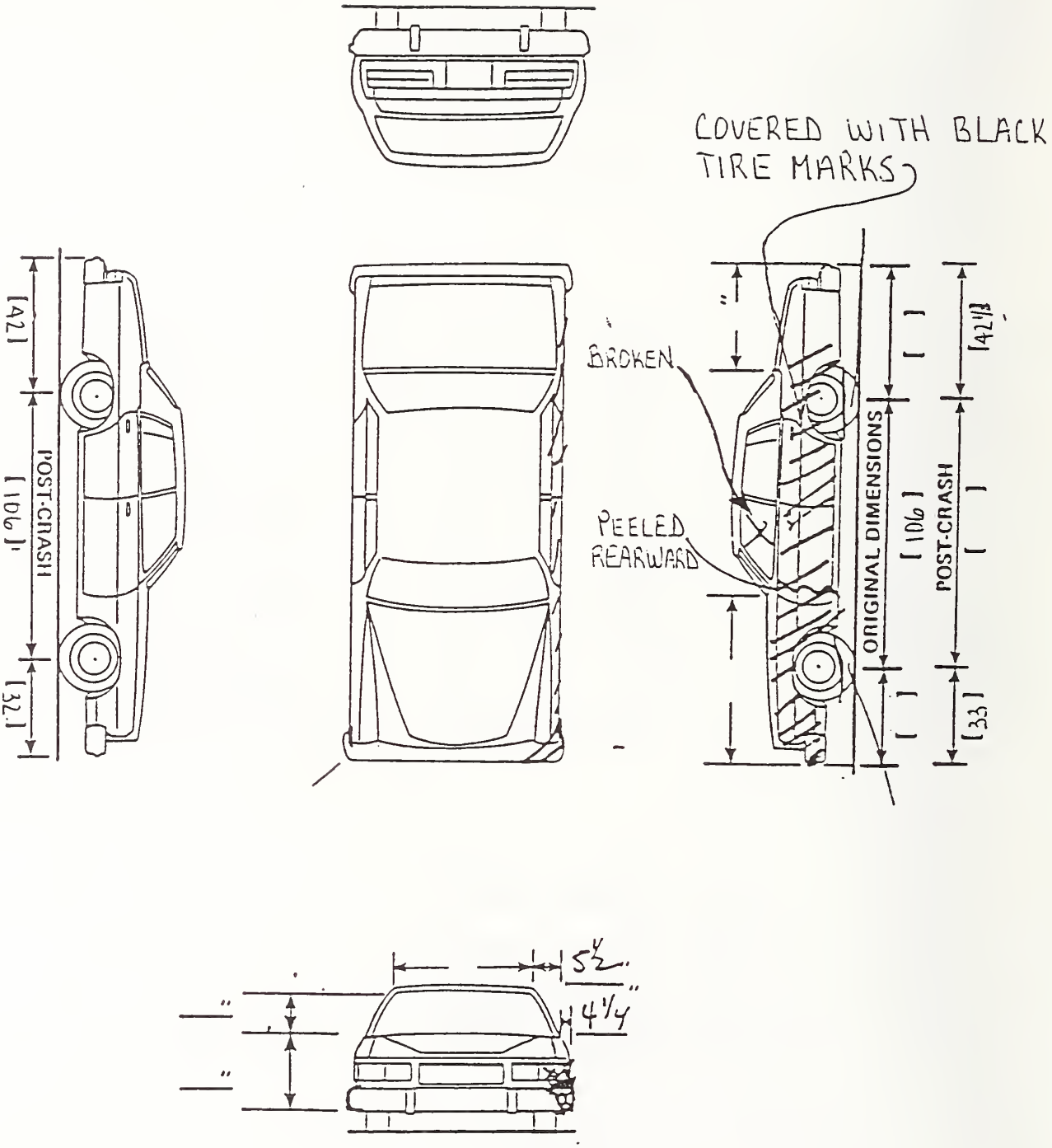
2 LUG BOLT BENT



FIBERGLASS CRACKED

CASE # 24 214
PSU 53
1981

VEHICLE 2



YEAR: 1982
PSU: 05
CASENO: 143
NATWGT: 101.0

ACCIDENT DESCRIPTION:

Vehicle 1:'78 Mercury Cougar XR7, 2 door sedan, hardtop, 4200 lb_f, 3 occupants.

Vehicle 2:'78 Mack CBE, 23500 lb_f, 1 occupant.

Impact Angle:-5 deg

Geometric Factor:0.6

Override Factor:0.2

Vehicle 1 crosses centerline on a 2 lane road (speed limit 50 mph) to pass a vehicle. Vehicle 1 collides with oncoming vehicle 2. Left front of vehicle 1 contacts left front of vehicle 2. The collision is very severe and debris is scattered on both shoulders. Vehicle 2 is not inspected.

OCCUPANTS:

Vehicle 1:Driver, male, 18 yrs, 185 lb_f, lap+shoulder restraint not used.
Right front passenger, female, 17 yrs, 115 lb_f, lap+shoulder restraint not used.
Right front passenger, female, 1 yrs, 20 lb_f, restraint not available.

Vehicle 2:Driver, male, 49 yrs, 225 lb_f, lap belt not used.

DAMAGE:

Vehicle 1:
Location: Front
Direction of force: 12 clock direction
Deformation: Extensive, demolished, frame bent, windshield and door integrity loss. The front left of the vehicle is pushed back to the A-pillar (by at least 60 inches).
Intrusion: Intrusion through 2 or more areas (left A-pillar, dash, steering column), intrusion greater than 15 cm.
Ejection: Both left front passengers completely ejected through right front door.
Contact locations: There is evidence of contact with left A-pillar, left door panel, steering column (driver chest), lower right dash (passenger knee), right door panel.
% Engaged: 100 % of front

Vehicle 2:
Location: Front
Direction of force: 12 clock direction
Deformation: Vehicle not inspected
Intrusion: No intrusion
Ejection: none
Contact locations: unknown
% Engaged: Unknown

ΔV:

Vehicle 1: 89 mph. (from momentum)

Vehicle 2: 16 mph. (,,)

INJURIES:

Vehicle 1: Driver: Killed. Skull fracture ais 2, neck cervical spine fracture ais 2, chest fracture ais 1, whole body abrasions ais 1, all sources of injury unknown.

Female 17 yrs: Transported and released. Left face, elbow contusion and abrasion, thigh contusion and abrasion, ais 1; head concussion, ais 2 . All sources of injury are unknown.

Female 1 yrs: Transported and released. Head concussion ais 2, right side contusion of the head ais 1. All sources of injury are unknown.

Vehicle 2: Driver: Transported and released. Upper face, right leg abrasions, ais 1. All sources of injury are unknown.

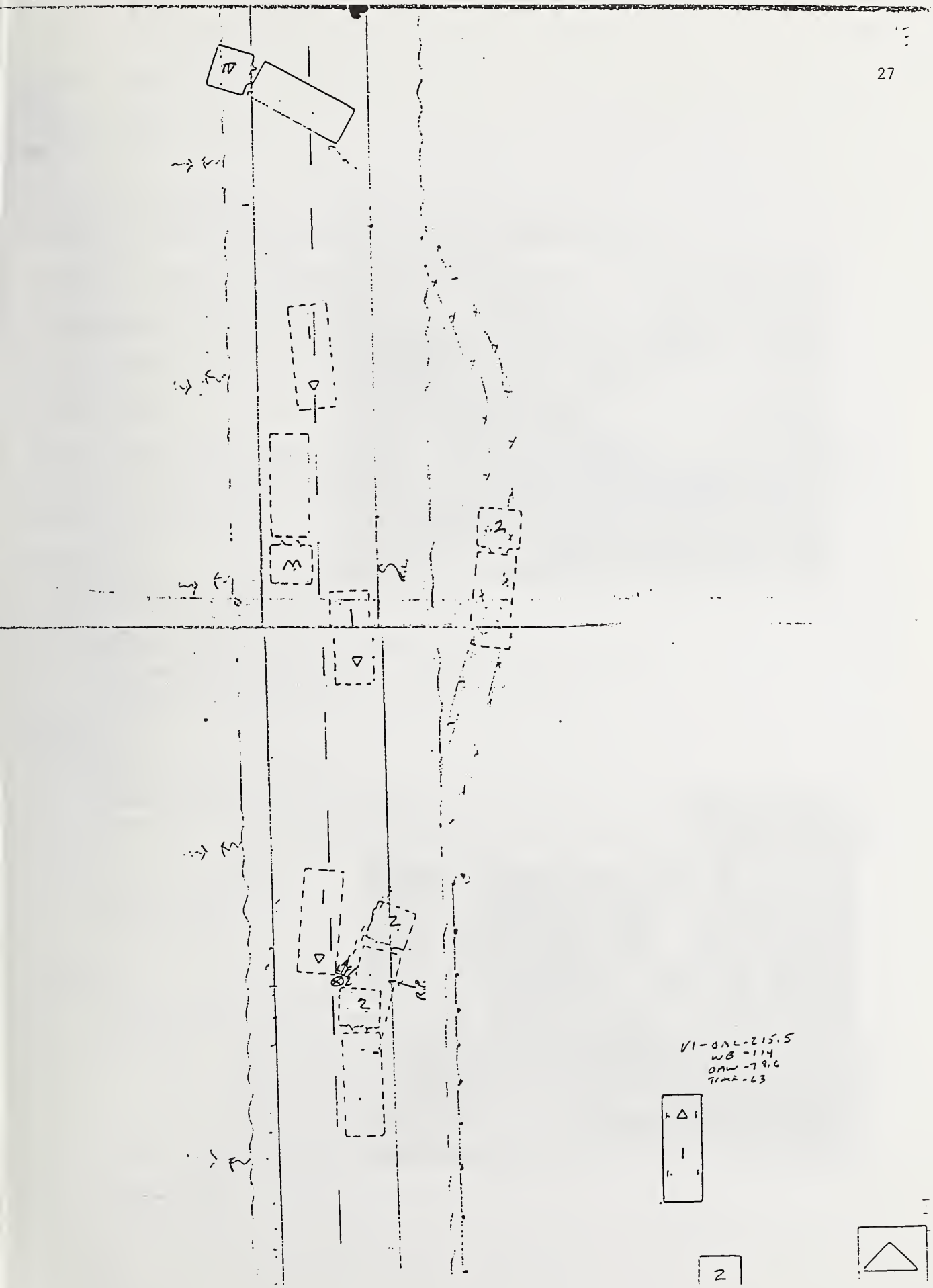
INJURY MITIGATION AND COMMENTS:

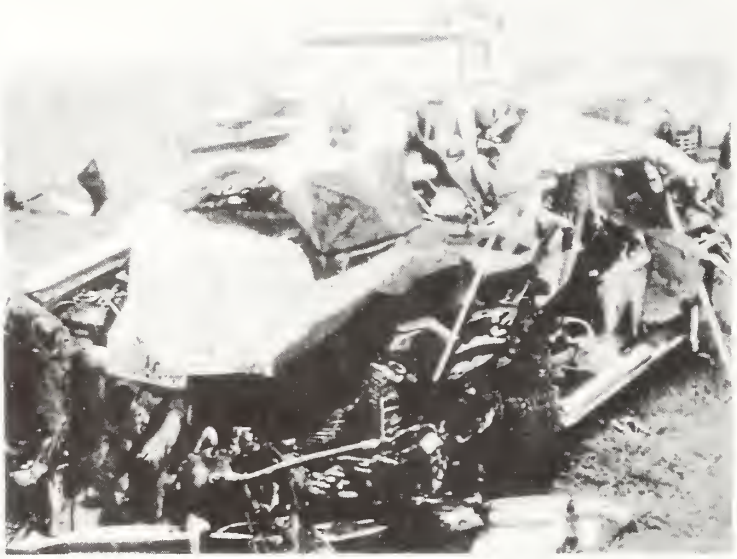
The damage to vehicle 1 is very severe. The driver had very severe injuries and was DOA. Photographs indicate total destruction of the vehicle, specially the left front of the vehicle. CRASH3 could not be used as the entire front of the vehicle was demolished and the amount of crush could not be estimated. There was a substantial amount of intrusion into the left front (driver) area. The firewall and the steering column had significant intrusion into the passenger compartment.

The heavy truck was not inspected. However, there seems to be no indication of geometric aggressivity (override) as the entire front of the car seems to be crushed up to the A-pillar. Truck front-end modifications such as lowering the bumper and/or softening the front structure are unlikely to reduce the amount of damage and intrusion in vehicle 1.

Also, the extent of damage to the passenger car suggests that high speeds were involved in this case, leading to the conclusion that a structure designed to deflect the passenger car out the truck's path may not work as theorized.

The driver of the heavy truck suffered minor injuries.


VI-ORL-215.5
WB-114
ORW-78.6
TRK-63



YEAR: 1982
PSU: 54
CASENO: 116
NATWGT: 107.8

ACCIDENT DESCRIPTION:

Vehicle 1: '78 Ford LTS-Series medium/heavy single unit truck, CBE, 1 occupant.

Vehicle 2: '80 Oldsmobile Delta 88 station wagon, 4100 lb_f, 4 occupants.

Impact Angle: -30 degrees

Geometric Factor: 1.0

Override Factor: 0.2

Vehicle 1, heading south on a two lane road (speed limit 55 mph), crosses centerline and strikes oncoming vehicle 2. Front left corner of vehicle 1 strikes vehicle 2 in front left corner. Vehicle 2 rotates counterclockwise and comes to rest in shoulder. Vehicle 1 continues to travel south and eventually comes to rest. It is estimated that both vehicles were traveling 55 mph.

OCCUPANTS:

Vehicle 1: Driver, male, 27 yrs, 185 lb_f, manual lap belt not used.

Vehicle 2: Driver, male, 43 yrs, manual lap+shoulder belt not used.
Middle front passenger, male, 9 yrs, lap belt not used.
Right front passenger, female, 41 yrs, manual lap+shoulder belt not used.
Left second-seat passenger, male, 7 yrs, manual lap belt not used.

DAMAGE:

Vehicle 1:

Location: Front end of vehicle
Direction of force: 1 o'clock direction
Deformation: Direct damage to entire lower front end. Entire front bumper scratched and dented. Frame and front axle dented. Damage to fiberglass fender on right side. Front grill is cracked.
Intrusion: No intrusion
Ejection: None.
% Engaged: 25%

Vehicle 2:

Location: Front left corner extending along left side to passenger door
Direction of force: 11 o'clock direction
Deformation: Extensive damage to front left corner and left side of vehicle. Body panels removed from left side of vehicle. Left side of bumper torn from attachment. Engine hood separated from latch. Driver door separated from latch. Left A, B and C pillars pushed inward. Passenger compartment roof is crushed. Front left wheel pushed inward. integrity loss through driver door and all left side windows.
Intrusion: Left passenger and driver doors greater than 15 cm. Left side of passenger compartment roof greater than 15 cm.
Ejection: None
% engaged: 10%

ΔV:

Vehicle 1: Not calculated.

Vehicle 2: Not calculated.

INJURIES:

Vehicle 1: Driver: contusion on left shoulder - ais 1, abrasions on upper back - ais 1.

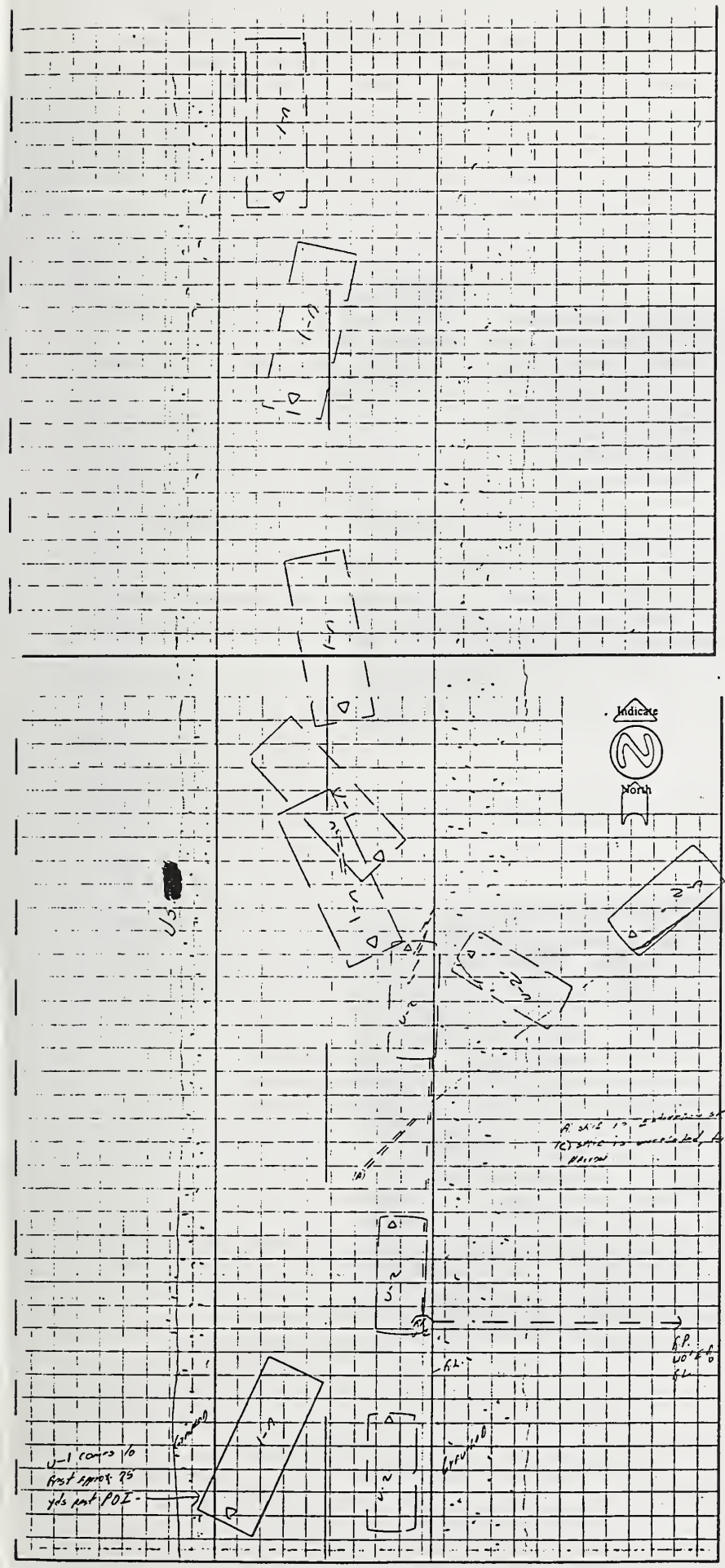
Vehicle 2: Driver: cerebral concussion - ais 5, upper facial lacerations - ais 1.
Middle front passenger: contusions on abdomen - ais 1, abrasions on lower leg - ais 1.
Right front passenger: fractured right ankle - ais 2, upper and lower facial lacerations-ais 1, upper left arm lacerations-ais 1, contusions on abdomen-ais 1.
Left second-seat passenger: lacerations on upper head - ais 1.

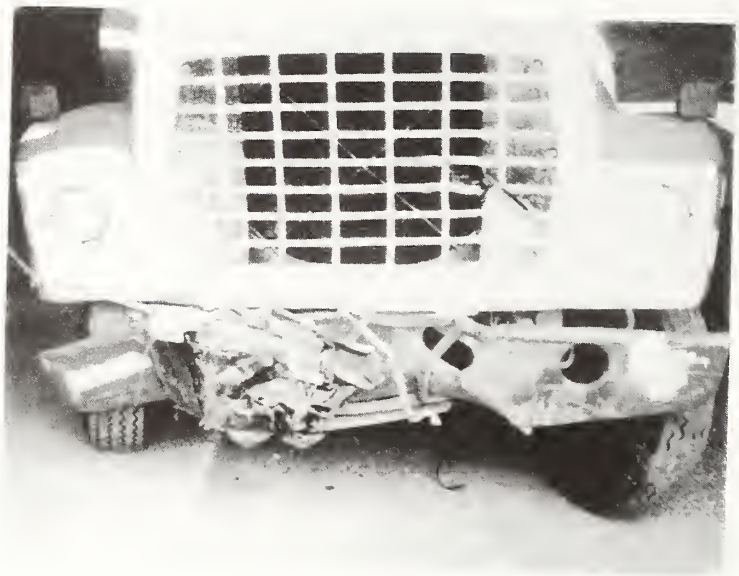
INJURY MITIGATION AND COMMENTS:

The large difference between the vehicles' stiffness is evident when comparing the damage of both vehicles. Making the truck's front end softer should reduce the severity of damage in impacts of this type.

There does not appear to be any evidence of truck override in this case. Therefore, it is concluded that lowering the truck's bumper would not have provided any additional reduction in the impact severity.

The damage distribution and impact angles described in the accident report suggests that the passenger car rotated into the path of the truck after initial contact. A deflecting structure on the truck's front end may actually increase the impact severity by providing less area over which the impact occurs.


Indicate
North



Flipped Pi
X
No!!.

YEAR: 1982
PSU: 53
CASENO: 227
NATWGT: 48.2

ACCIDENT DESCRIPTION:

Vehicle 1: '77 Buick Riviera, 2-door sedan, hardtop, 3900 lb_f, 1 occupant.

Vehicle 2: '79 Ford CLT-series, medium/heavy truck pulling one trailer, COE, 2 occupants.

Impact Angle: 10 degrees

Geometric Factor: 0.20

Override Factor: 0.40

Vehicle 1, heading east on a two lane road (speed limit 50 mph), crosses centerline and strikes oncoming vehicle 2. Left front corner of vehicle 2 strikes front center of vehicle 1. After initial impact, vehicle 1 rotates counterclockwise and comes to rest. Travel speeds are unknown.

OCCUPANTS:

Vehicle 1: Driver, male, 21 yrs, 175 lb_f, manual lap+shoulder belt not used.

Vehicle 2: Driver, male, 40 yrs, 170 lb_f, manual lap belt not used.
Right front passenger, male, 36 yrs, 180 lb_f, manual lap belt not used.

DAMAGE:

Vehicle 1:
Location: Front end extending into passenger compartment
Direction of force: 12 o'clock direction
Deformation: Extensive damage to front end and passenger compartment. Engine hood and left front fender torn off. Both A-pillars pushed rearward. Passenger compartment roof is buckled. Passenger and driver doors pushed rearward. Instrument panel pushed rearward. Integrity loss through front and side passenger compartment windows and doors.
Intrusion: Intrusion to passenger compartment floor and instrument panel greater than 15 cm.
Ejection: None
% engaged: 100%

Vehicle 2:
Location: Front left end of vehicle
Direction of force: 12 o'clock direction
Deformation: Front bumper scratched and dented. Left bumper corner bent back around frame attachment point. Left front tire exposed and flat. Part of fiberglass engine cover above left bumper corner missing. Front grill cover missing.
Intrusion: No intrusion
Ejection: None.
% Engaged: 40%

ΔV:

Vehicle 1: 83.7 mph (using momentum, assuming truck mass to be 20,000 lb_f)

Vehicle 2: 16.3 mph (,,)

INJURIES:

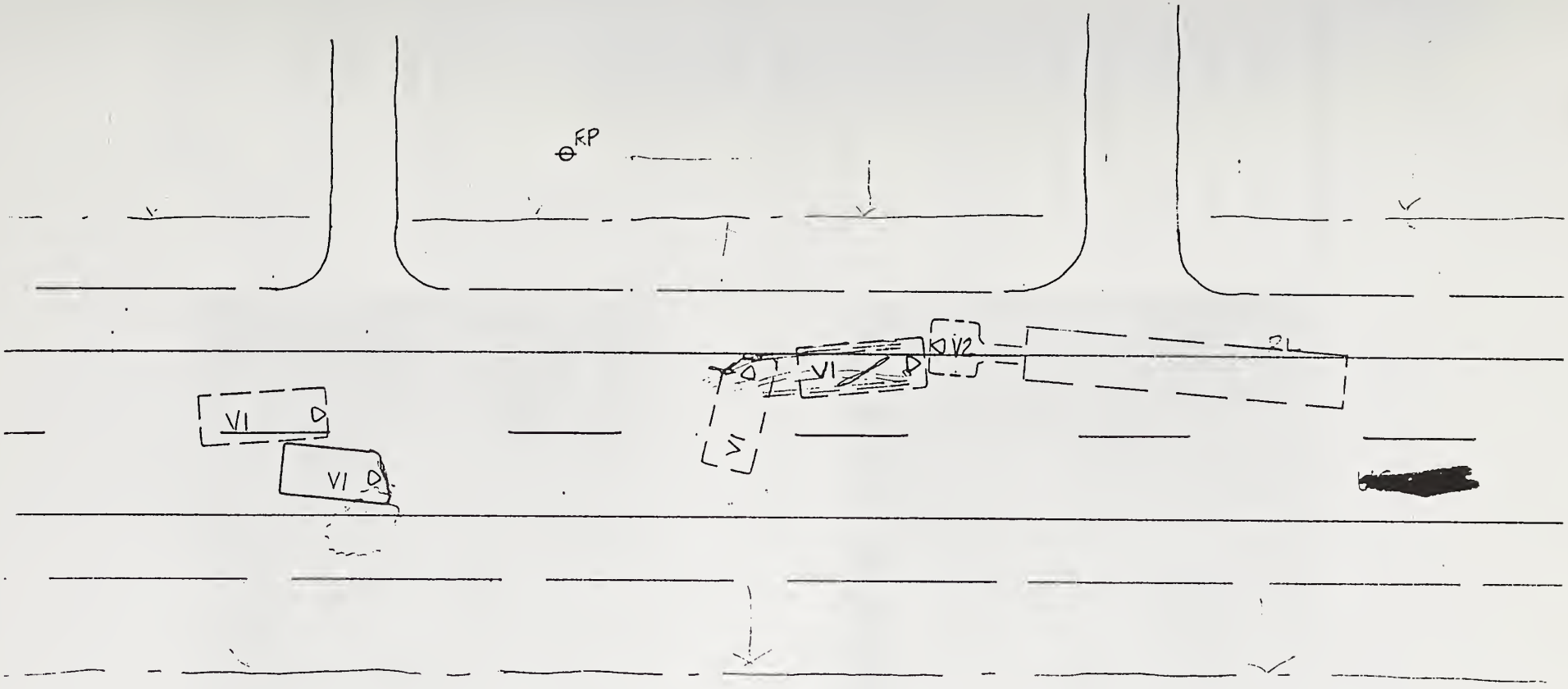
Vehicle 1: Driver: fatal head injuries - ais 7.

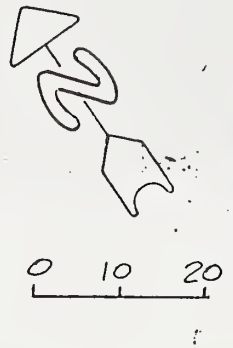
Vehicle 2: Driver: abrasions on left wrist - ais 1.
Right front passenger: no injuries

INJURY MITIGATION AND COMMENTS:

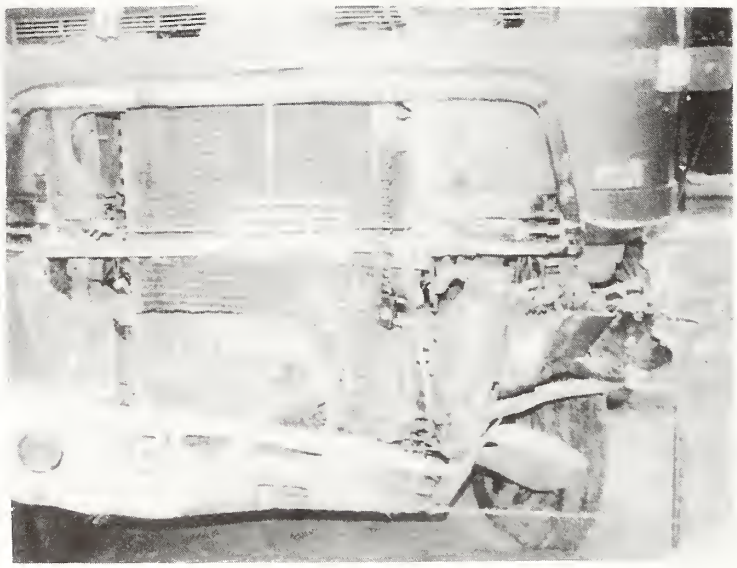
Comparing the damage patterns between the passenger car and truck suggests that truck override may have occurred and demonstrates the difference between the vehicle's stiffness. Lowering the truck's front end and making it softer may provide a significant reduction in the extent of damage to the passenger car.

Due to the apparent high speeds and vehicle overlap involved in the collision it is unlikely that a deflecting structure mounted on the front of the truck would work according to theory in this case.





[redacted] NASS	
PSU 53	: 227J
1"= 20'	: 11-82



YEAR: 1982
PSU: 53
CASENO: 103
NATWGT: 80.4

ACCIDENT DESCRIPTION:

Vehicle 1: '81 Mercury Zephyr, 4-door sedan, hardtop, 2700 lb_f, 1 occupant.

Vehicle 2: '73 Kenworth, medium/heavy truck pulling one trailer, CBE, 1 occupant.

Impact Angle: 0 degrees

Geometric Factor: 0.40

Override Factor: 0.30

Vehicle 1, heading west on a two lane road (speed limit 45 mph), crosses centerline and strikes oncoming vehicle 2 head on. Left front half of vehicle 2 strikes left front half of vehicle 1. After initial impact, vehicle 1 rotates counterclockwise and comes to rest. Travel speeds are unknown.

OCCUPANTS:

Vehicle 1: Driver, male, 36 yrs, 250 lb_f, manual lap+shoulder belt not used.

Vehicle 2: Driver, male, 36 yrs, manual lap belt not used.

DAMAGE:

Vehicle 1:
Location: Front end and left side extending into passenger compartment
Direction of force: 12 o'clock direction
Deformation: Extensive damage to front end, left side and passenger compartment. Engine hood, left front fender and left front and rear doors torn off. Left A and C-pillars pushed inward. B-pillar completely removed. Passenger compartment roof is buckled and pushed downward. Front axle pushed rearward into firewall. Instrument panel pushed rearward. Integrity loss through front windshield and left side driver and passenger windows and doors.
Intrusion: Intrusion to passenger compartment floor and instrument panel greater than 15 cm.
Ejection: Partially ejected through driver door.
% engaged: 50%

Vehicle 2:
Location: Left front end of vehicle
Direction of force: 12 o'clock direction
Deformation: Left half of bumper sheared off at frame attachment point. Left front tire missing. Fiberglass fender over left tire missing and engine cover cracked.
Intrusion: No intrusion
Ejection: None.
% Engaged: 30%

ΔV:

Vehicle 1: Not calculated.

Vehicle 2: Not calculated.

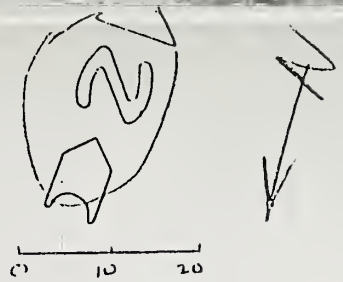
INJURIES:

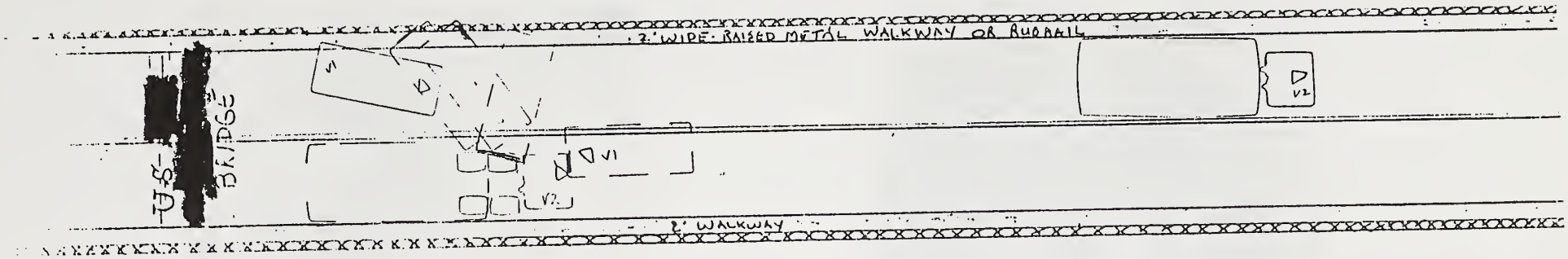
Vehicle 1: Driver: fatal head injuries - ais 7, left thigh bone fractured - ais 3, upper left arm lacerations - ais 1.

Vehicle 2: Driver: no injuries.

INJURY MITIGATION AND COMMENTS:

Due to the apparent high speeds involved in the collision it is unlikely that any feasible truck front-end modifications could reduce the severity of vehicle damage and occupant injuries in this case.





[redacted] NASS 53	CNS	CASE 1083	6-1-82	1" = 20'

YEAR: 1983
PSU: 80
CASENO: 25
NATWGT: 108.0

ACCIDENT DESCRIPTION:

Vehicle 1: '76 Jeep Wagoneer, 4 door MPV, CW=4250 lb_f, 1 occupant

Vehicle 2: '82 GMC General CBE w/flatbed trailer, CW=27000 lb_f, less than 50 lb_f of cargo, 1 occupant

Impact Angle: 0 deg

Geometric Factor: 0.5

Override Factor: 0.4

On a two lane roadway (speed limit 50 mph.), vehicle 1 veered into the same lane as vehicle 2, impacted it on its left front in a quarter offset mode.

OCCUPANTS:

Vehicle 1: Driver: female, 18 yrs., restrained (lap+shoulder belt). She was entrapped in the vehicle due to steering wheel contact.

Vehicle 2: Driver: no information available

DAMAGE:

Vehicle 1:

Location: Front
Direction of force: 12 clock direction
Deformation: Front left side of vehicle 1 was crushed approx. 37 inches. The crush occurred on the fender level above the bumper. The left fender was pushed back the entire length of the front end. Compartment integrity was lost through the windshield.
Intrusion: Through the floorpan (> 6 inches)
Ejections: None
Contact locations: Steering assembly and instrument panel
% Engaged: 20 % of front

Vehicle 2:

Location: Front
Direction of force: 12 clock direction
Deformation: Some damage to the left front bumper and fender. Power steering cylinder and gas tank were dislodged.
Intrusion: None
Ejections: None
Contact locations: None
% Engaged: unknown

ΔV:

Vehicle 1: 18.23 mph.
Vehicle 2: not calculated

INJURIES:

Vehicle 1: Driver: sustained fractures to the nose and jaw (AIS 3) due to contact with the steering assembly. She was hospitalized for 7 days.

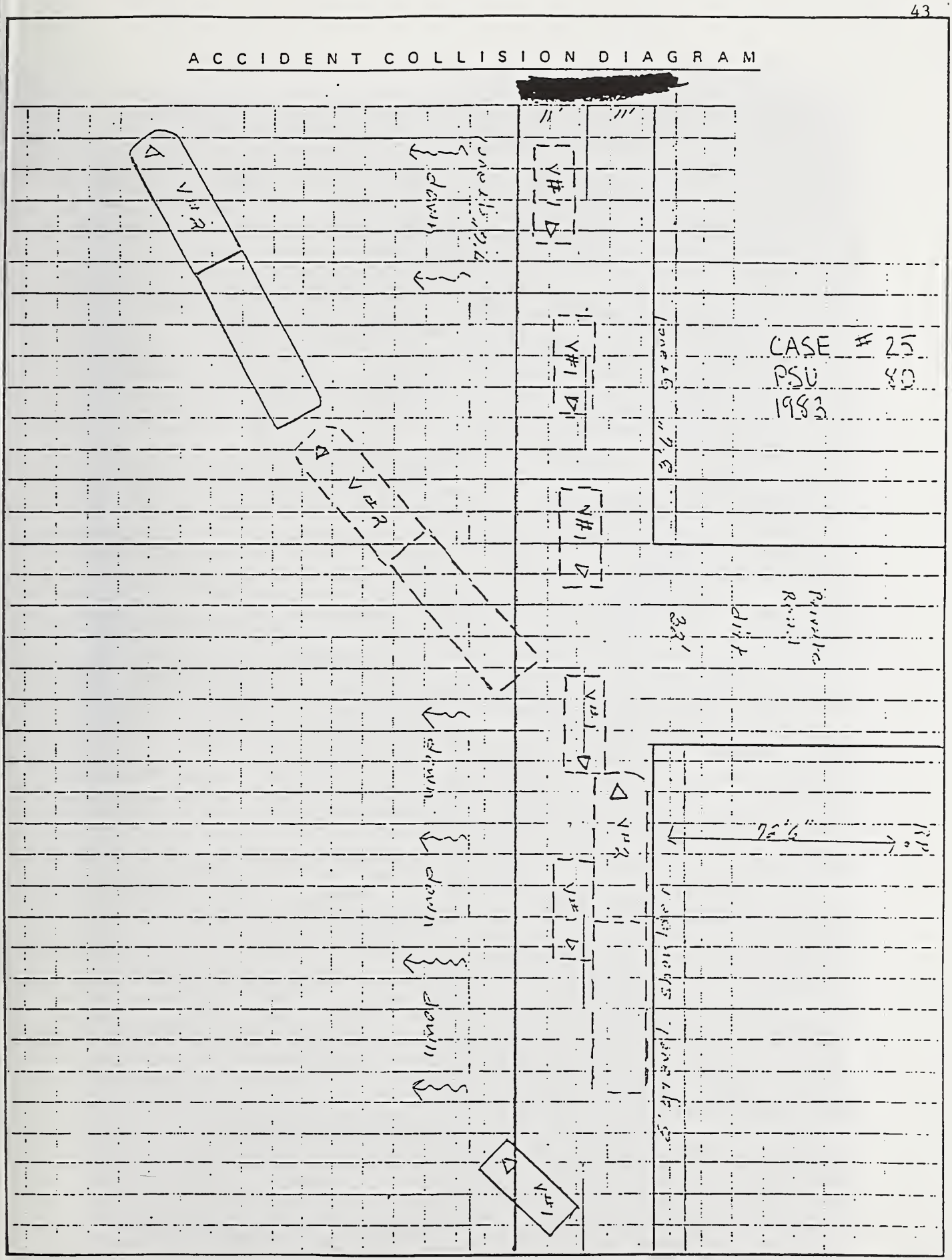
Vehicle 2: None

INJURY MITIGATION AND COMMENTS:

The damage to vehicle 1 can be attributed to the geometric mismatch between the two vehicles and the extremely stiff truck bumper. This was evident here because the Jeep's fender area above the bumper was crushed rearward, thus not enabling the lower half of the structure to absorb any of the energy. This caused the intrusion of the floorpan which ultimately resulted in the steering wheel intruding into the compartment and entrapping the driver.

The availability of a modified heavy truck front end which is lower and more compliant would allow some of the energy to be absorbed by the truck. It would also allow the front end of the Jeep to absorb more energy with less deformation and intrusion. The truck bumper should also be structured so as to allow the Jeep to deflect from the bumper and dissipate its excess kinetic energy elsewhere.

ACCIDENT COLLISION DIAGRAM



YEAR: 1983
PSU: 53
CASENO: 102
NATWGT: 60.3

ACCIDENT DESCRIPTION:

Vehicle 2: '79 Brockway CBE, 22750 lb_f(assumed), 1 occupant

Vehicle 3: '82 Ford Mustang, 2 door hatchback, 2776 lb_f, 3 occupants

Impact Angle: -20 deg

Geometric Factor: 0.7

Override Factor: 0.7

On a two lane road (speed limit 40 mph), Vehicle 1 (not described) rear-ended vehicle 2, which was pushed into the oncoming traffic lane. Vehicle 2 was then hit by the oncoming vehicle 3 in a front-to-front offset impact. The front left side of vehicle 3 was engaged by the front left side of vehicle 2.

OCCUPANTS:

Vehicle 2: Driver: male, 29 yrs., lap belt not used.

Vehicle 3: Driver: female, 31 yrs, 140 $_f$, lap+shoulder belt not used, entrapped.
Right front passenger: female, 23 yrs, 170 lb_f, lap+shoulder belt not used.
Right rear passenger: female, 42 yrs, 117 lb_f, lap belt not used.

DAMAGE:

Vehicle 2:

Location: Front
Direction of force: 1 clock direction
Deformation: Left front bumper (beyond the frame attachment point) bent back, left side of the grill is pushed in, damage to the left fender below the headlight, left front wheel is bent back with damage to the axle.
Intrusion: None
Ejections: None
Contact locations: None
% Engaged: 40 % of front

Vehicle 3:

Location: Front
Direction of force: 11 clock direction
Deformation: Substantial damage to the left front, roof and sill buckled, the hood is pushed back and has indications (scrape marks, tire crush mark) of override by the truck left front tire. Integrity was lost through the windshield and front door.
Intrusion: Front (steering column, dash..) intruded by greater than 15 cams on the drivers side. The A-pillar and steering column also intruded into the driver side of the passenger compartment.
Ejections: None
Contact locations: there was contact with lower left dash, steering wheel, gearshift lever, glove box, passenger side windshield.
% Engaged: 60 % of front.

ΔV:

Vehicle 2: 4.34 mph.

Vehicle 3: 35.6 mph.

INJURIES:

Vehicle 2: Driver: Not injured.

Vehicle 3: Driver: Killed. Head concussion critical injury AIS 5, multiple injuries, never regained consciousness.

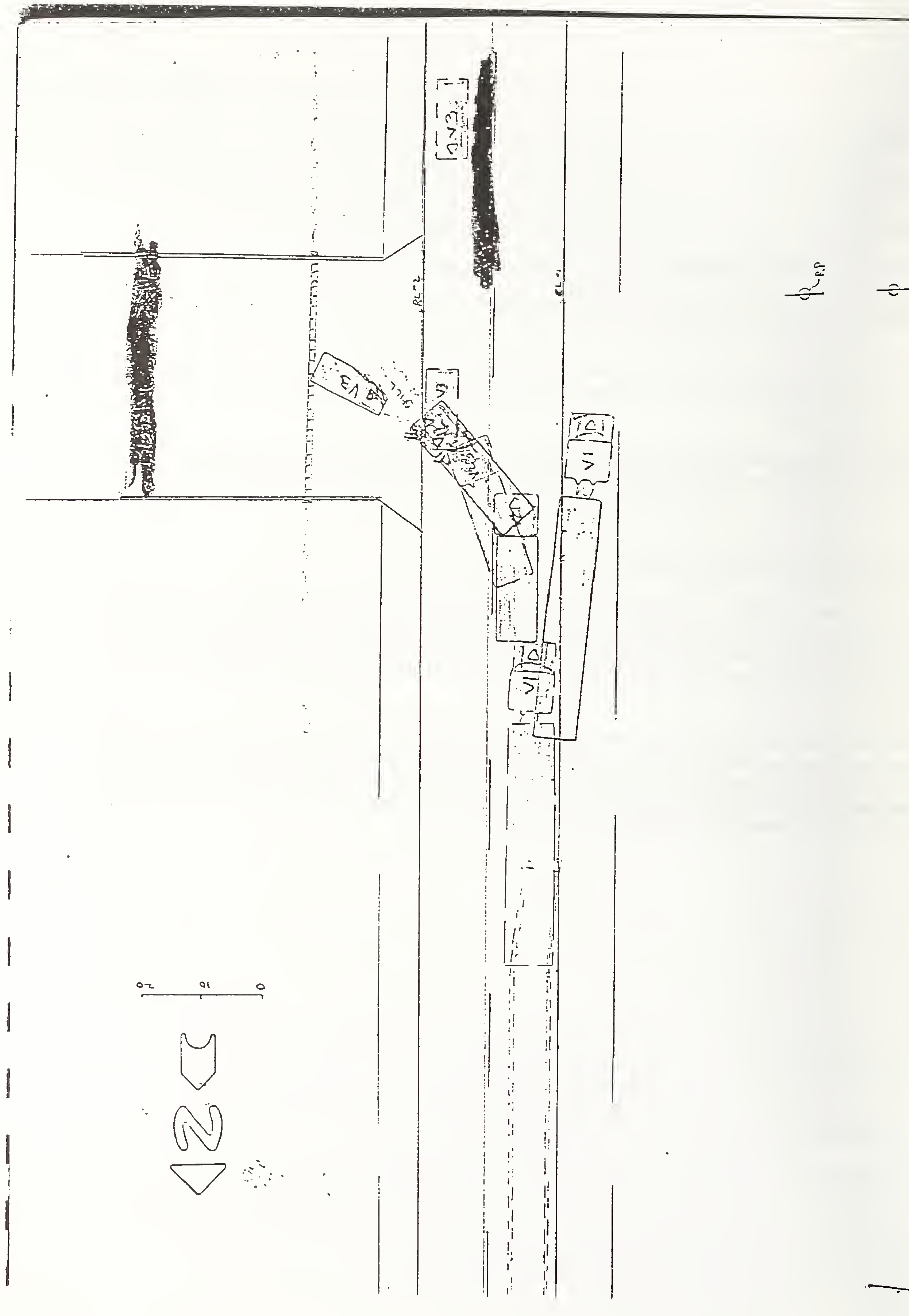
Right front passenger: Hospitalized, lacerated left knee due to lower dash/instrument panel AIS 1, lacerations on the face and head due to windshield AIS 1, lacerated lower face due to windshield AIS 1.

Right rear passenger: Hospitalized (13 days), severe concussion AIS 3, fracture of face AIS 3, right lower leg fracture due to seat back support AIS 3, right thigh fracture due to seat back support AIS 3.

INJURY MITIGATION AND COMMENTS:

The front left of vehicle 3 was damaged severely by the truck front left bumper and wheel. The truck wheel overrode the vehicle, the truck grill pushing the A-pillar and roofline of the car into the passenger compartment. The passengers were injured because of contact with the windshield and front seat and being unbelted. The driver side of the passenger compartment had significant intrusion, and contact with dash, windshield, and steering column.

The loss of integrity of the passenger compartment would be reduced if the truck bumper had engaged the car bumper, and not overridden the car. The damage would also be spread over the entire front of the car. Therefore, the front of the truck should be lowered and softened to reduce the severity of the crash-pulse experienced by the car. Also. because of the type of collision (1/3 rd overlap offset impact), a device to deflect the car off the truck may also prove useful.


V3
V1

YEAR: 1983
PSU: 30
CASENO: 12
NATWGT: 132.1

ACCIDENT DESCRIPTION:

Vehicle 1: '76 Chevrolet Blazer light truck, 4306 lb_f, one occupant.

Vehicle 2: '80 Mack COE truck, 14,200 lb_f, one occupant.

Impact Angle: -10 deg.

Geometric Factor: 0.6

Override Factor: 0.1

Vehicle 1 was driving on the wrong side of a divided highway (55 mph speed limit) when struck headon by vehicle 2. Vehicle 1 bounced off into the grassy median where it rolled over.

OCCUPANTS:

Vehicle 1: Driver, male, 23 yrs, 190 lb_f, lap belt not used

Vehicle 2: Driver, male, 34 yrs, 185 lb_f, lap belt used

DAMAGE:

Vehicle 1:
Location: Front
Direction of force: 11 o'clock
Deformation: There is substantial damage to the front, with the bumper pushed back almost 40 inches on the driver side. Integrity was lost through the windshield.
Intrusion: The front (steering column, dash) had more than 15 cams of intrusion. The driver was entrapped.
Ejections: None
Contact locations: Steering wheel and column, instrument panel.
% Engaged: 50 % of front

Vehicle 2:
Location: Front
Direction of force: 1 o'clock
Deformation: The truck bumper was buckled and left fender crushed in. The fender above the left wheel (with the headlight) was torn off. The left suspension was also bent inward.
Intrusion:None
Ejections: None
Contact locations: Side instrument panel, visor, steering column.
% Engaged: 30 % of front.

ΔV:

Vehicle 1: 14.8 mph.

Vehicle 2: 4.5 mph.

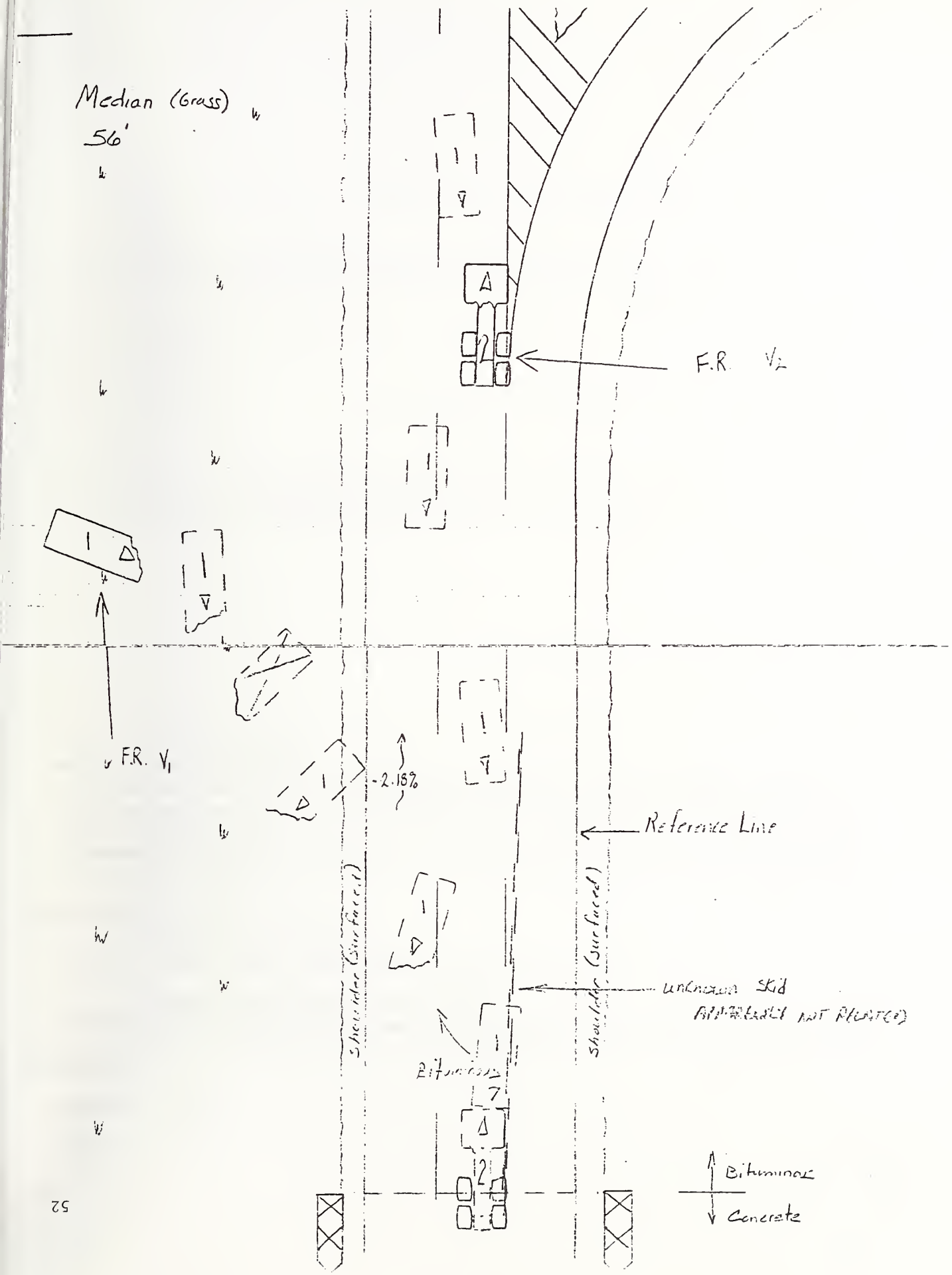
INJURIES:

Vehicle 1: Driver, hospitalized, ruptured bowel AIS 5, lacerated liver AIS 4, left arm fractured AIS 3, lacerated chest, shoulder, lip, right knee AIS 1.

Vehicle 2: Driver, contusion of right shoulder, knee, temple, left wrist AIS 1

INJURY MITIGATION AND COMMENTS:

From the amount of damage to the pickup and the truck, this appears to be a very severe impact. The amount of intrusion into the driver side of the pickup is very large (the driver was wedged in the seat by the steering wheel). The bumper structure of the pickup seems to have been engaged by the truck. Therefore, lowering of the truck front would not have made any significant difference. However, energy absorption by the truck would have helped. Also, from the damage location on both vehicles, and the post impact trajectory of the pickup, it seems that a deflecting truck front geometry would have increased the likelihood of the pickup rotating into the path of the truck.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56'
F.R. V2
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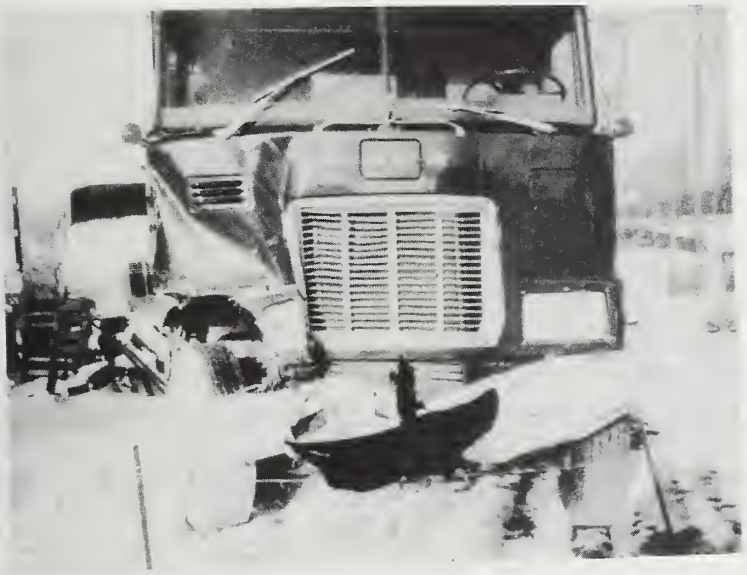

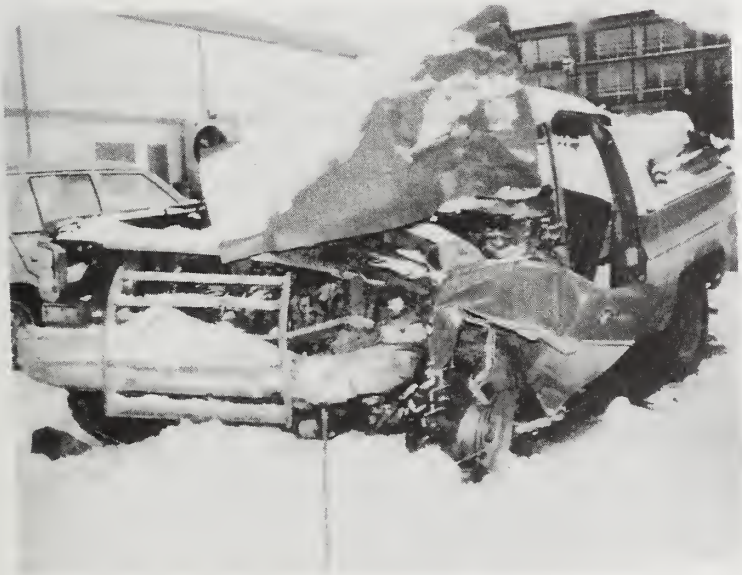

YEAR: 1983
PSU: 53
CASENO: 200
NATWGT: 144.7

ACCIDENT DESCRIPTION:

Vehicle 1: '81 Chevrolet LUV pickup, 4-door sedan hardtop, 2375 lb_f, 1 occupant.

Vehicle 2: '77 medium/heavy Freightliner truck pulling one trailer, COE, 1 occupant.

Impact Angle: 25 degrees

Geometric Factor: 0.0

Override Factor: 0.5

Vehicle 1, heading north on a two lane road (speed limit 40 mph), crosses centerline and into path of oncoming vehicle 2. Vehicles impact head on and off-center. Vehicle 1 spins counterclockwise out of path of vehicle 2 and comes to rest in median. Vehicle 2 continues off road and strikes side of built-up concrete driveway. Travel speeds are unknown.

OCCUPANTS:

Vehicle 1: Driver, male, 22 yrs, 145 lb_f, manual lap+shoulder belt not used.

Vehicle 2: Driver, male, 46 yrs, restraint system availability and use unknown.

DAMAGE:

Vehicle 1:
Location: Left front end extending into passenger compartment
Direction of force: 1 o'clock direction
Deformation: Extensive damage to front end and passenger compartment. Left front wheel and axle pushed rearward. Engine hood buckled rearward. Left A-pillar completely missing. Left B-pillar pushed rearward along with passenger compartment roof. Right A and B-pillar pushed inward. Left door missing. Vehicle bowed towards left. Integrity loss through all passenger compartment doors and windows.
Intrusion: Intrusion of instrument panel and compartment greater floor than 15 cm.
Ejection: Driver partially ejected through left door.
% engaged: 50%

Vehicle 2:
Location: Front left half of vehicle
Direction of force: 12 o'clock direction
Deformation: vehicle was not inspected.
Intrusion: Unknown
Ejection: None.
% Engaged: 40%

ΔV:

Vehicle 1: 42.8 mph (assuming mass of the truck to be 20,000 lb_f)

Vehicle 2: 5.1 mph (,,)

INJURIES:

Vehicle 1: Driver: fatal injuries, cerebral concussion - ais 5, multiple facial abrasions - ais 1, lacerations on left thigh, knee and ankle - ais 1.

Vehicle 2: Driver: contusion on right thigh - ais 1, contusion on chest - ais 1.

INJURY MITIGATION AND COMMENTS:

It is impossible to tell from the accident case if truck override did occur. However, a better geometric match is shown with the two vehicles involved in the impact and this may have prevented significant override. The pickup shows extensive damage. Although the truck was not examined it is likely that it did not have any significant damage to it. This would demonstrate the vast differences in the vehicle's front end stiffness properties. Softening the truck's front end is likely to reduce the damage extent to the pickup.

The accident diagram indicates that the pickup rotated out of the truck's path after initial impact. It is impossible to know how quickly this occurred, but it is feasible that, in accidents with impact collisions similar to those in this case, a truck with a deflecting structure on the front end may deflect the pickup more quickly, further reducing the damage severity.

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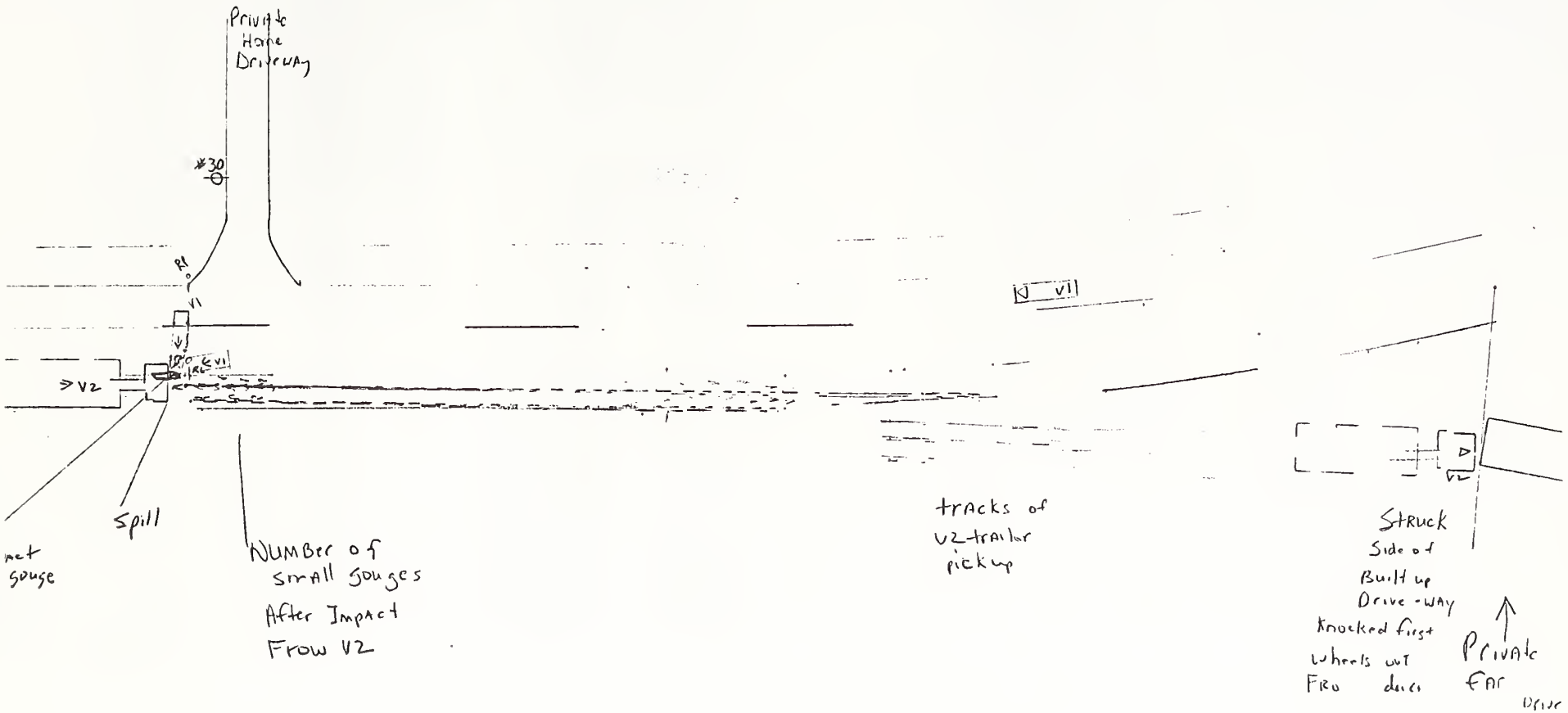
[redacted] 53- CNS

Case 200 J- [redacted]



YEAR: 1983
PSU: 08
CASENO: 289
NATWGT: 125.8

ACCIDENT DESCRIPTION:

Vehicle 1: '75 Chevrolet Suburban, 4-door, 4400 lb_f, 1 occupant.

Vehicle 2: '80 Ford Brockway single unit truck, 19100 lb_f, 1 occupant.

Impact Angle: 60 deg

Geometric Factor: 0.0

Override Factor: 0.0

Vehicle 1, traveling west on a 2 lane road (speed limit 50 mph), attempts to make a left-hand turn into a private drive and crosses into path of oncoming vehicle 2 traveling east. Full front-end of vehicle 1 strikes vehicle 2 in left corner of front bumper. Vehicle 1 rotates ccw and comes to final rest. Vehicle 2 rolls over onto roof and comes to rest. Travel speeds are unknown.

OCCUPANTS:

Vehicle 1: Driver, male, 19 yrs, 230 lb_f, manual lap+shoulder belt restraint not used.

Vehicle 2: Driver, male, 28 yrs, manual lap belt not used.

DAMAGE:

Vehicle 1:

Location: Front end
Direction of force: 1 o'clock direction
Deformation: Front bumper and grill pushed inward greater than 25 inches. Engine hood buckled backwards. Left, front fender buckled and torn. Integrity loss through front windshield.
Intrusion: Floor intruded more than 15 cm.
Ejection: None
% Engaged: 90 % of front

Vehicle 2:

Location: Left corner
Direction of force: 11 o'clock direction
Deformation: Lower, left side of engine hood torn away. Left side of front bumper bent back around frame attachment point. Left front tire exposed and pushed back and outward. Engine grill dented on left side.
Intrusion: No intrusion.
Ejection: None
% Engaged: 30 % of front

ΔV:

Vehicle 1: 43.25 mph.

Vehicle 2: 9.96 mph.

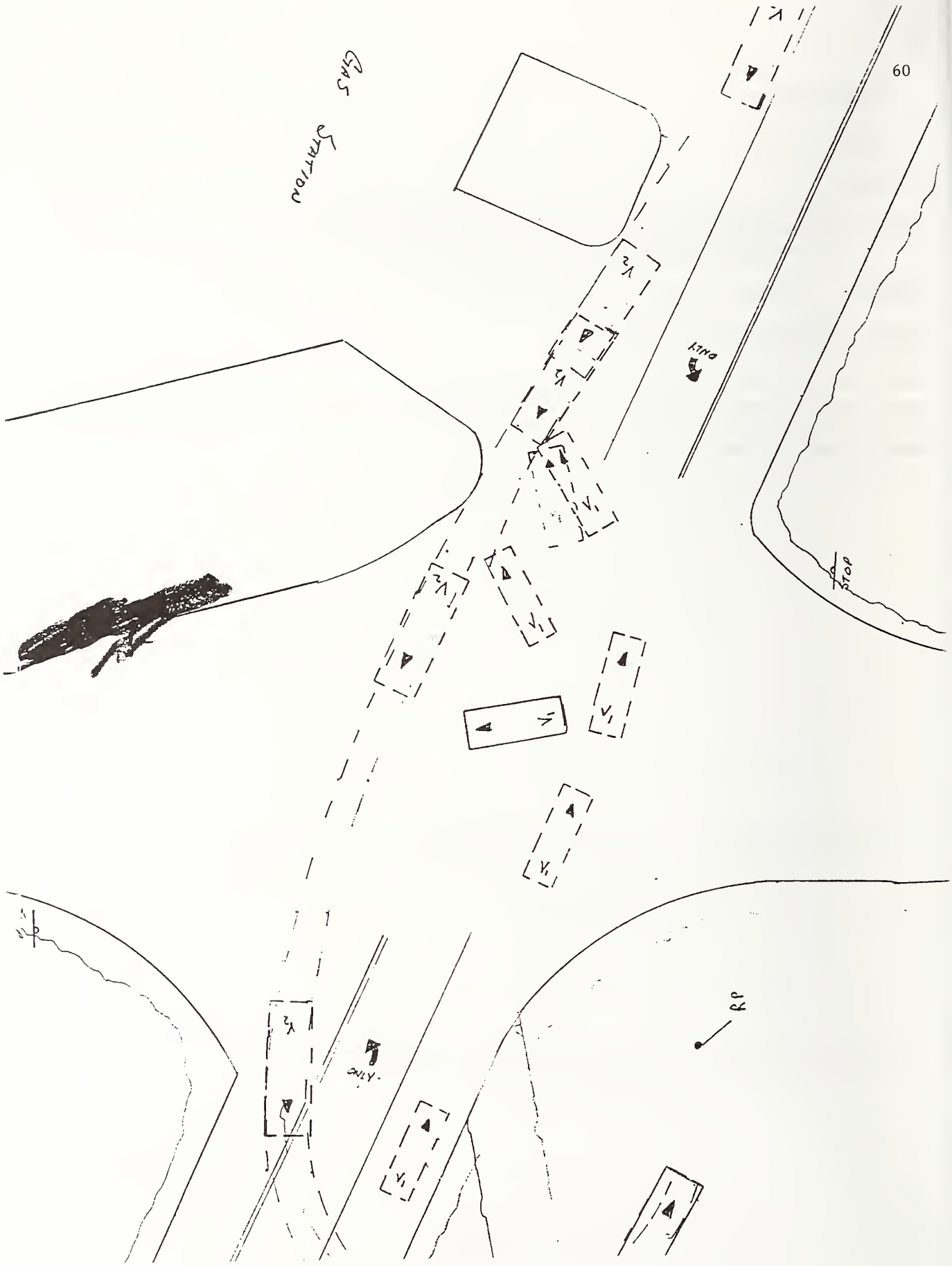
INJURIES:

Vehicle 1: Driver: right femur fractured - ais 3, abrasions on right knee - ais 1, abrasions on right forearm - ais 1, laceration on upper head - ais 1.

Vehicle 2: Driver: no injuries

INJURY MITIGATION AND COMMENTS:

There does not appear to be any evidence of truck override in this case possibly due to the fact that a better geometric match is present with the vehicles. However, softening the truck front end may help reduce the crash pulse on the car. Also, the geometry of the impact indicates that a deflecting bumper on the truck would be of some benefit in deflecting the car away from the truck.


ONLY
STOP

YEAR: 1983
PSU: 29
CASENO: 168
NATWGT: 158.9

ACCIDENT DESCRIPTION:

Vehicle 1: '75 Plymouth Duster, 2 door hardtop sedan, 3050 lb_f, 2 occupants.

Vehicle 2: '79 International Cargo Star COE, 16000 lb_f, 1 occupant.

Impact Angle: 0 deg

Geometric Factor: 0.2

Override Factor: 0.5

Vehicle 1 was heading the wrong way on a median divided highway (speed limit 50 mph), when struck head on by the oncoming vehicle 2. Driver of Vehicle 1 was legally intoxicated at the time of accident. The right front of vehicle 1 collided with the right front of vehicle 2 in a 1/3rd offset front to front impact. Vehicle 2 subsequently rolled over on to its left side.

OCCUPANTS:

Vehicle 1: Driver: male, 21 yrs, unknown weight, lap+shoulder belt not used.
Front right passenger: female, 19 yrs, unknown weight, lap+shoulder belt not used.

Vehicle 2: Driver:Male, 36 yrs, 180 lb_f, lap belt not used.

DAMAGE:

Vehicle 1:

Location: Left front
Direction of force: 12 clock direction
Deformation: The contact with the truck is to the right half of the bumper, damage across the entire height (bumper to hood), no indications of override. There is no integrity loss of the passenger compartment.
Intrusion: The steering column and dash intruded (> 15 cams)
Ejections: None
Contact locations: The steering wheel was pushed down and shifted to the right, the left visor dented and had blood stains, left windshield has circular webbing and hair, center dash radio and ashtray dented, right A-pillar dented and has skin transfer, right door panel and roofline has clothing transfer.
% Engaged: 50 % of front

Vehicle 2:

Location: Right front
Direction of force: 1 clock direction
Deformation: Right front corner of the bumper pushed back, Some damage to the right front fender. The right wheel-well cover is bent back. There is some damage to the right wheel suspension.
Intrusion: None
Ejections: None
Contact locations: Left door bent, dash, steering wheel and roof bent on the left side. Note that these are probably caused by the truck rolling over on to its left side.
% Engaged: 40 % of front

ΔV:

Vehicle 1: 28 mph.

Vehicle 2: 5.3 mph.

INJURIES:

Vehicle 1: Driver: Transported and released. Concussion AIS 2, teeth in upper and lower jaw fractured AIS 1, caused by windshield, lacerated right hand, lacerated knees, AIS 1, caused by contact with dash.

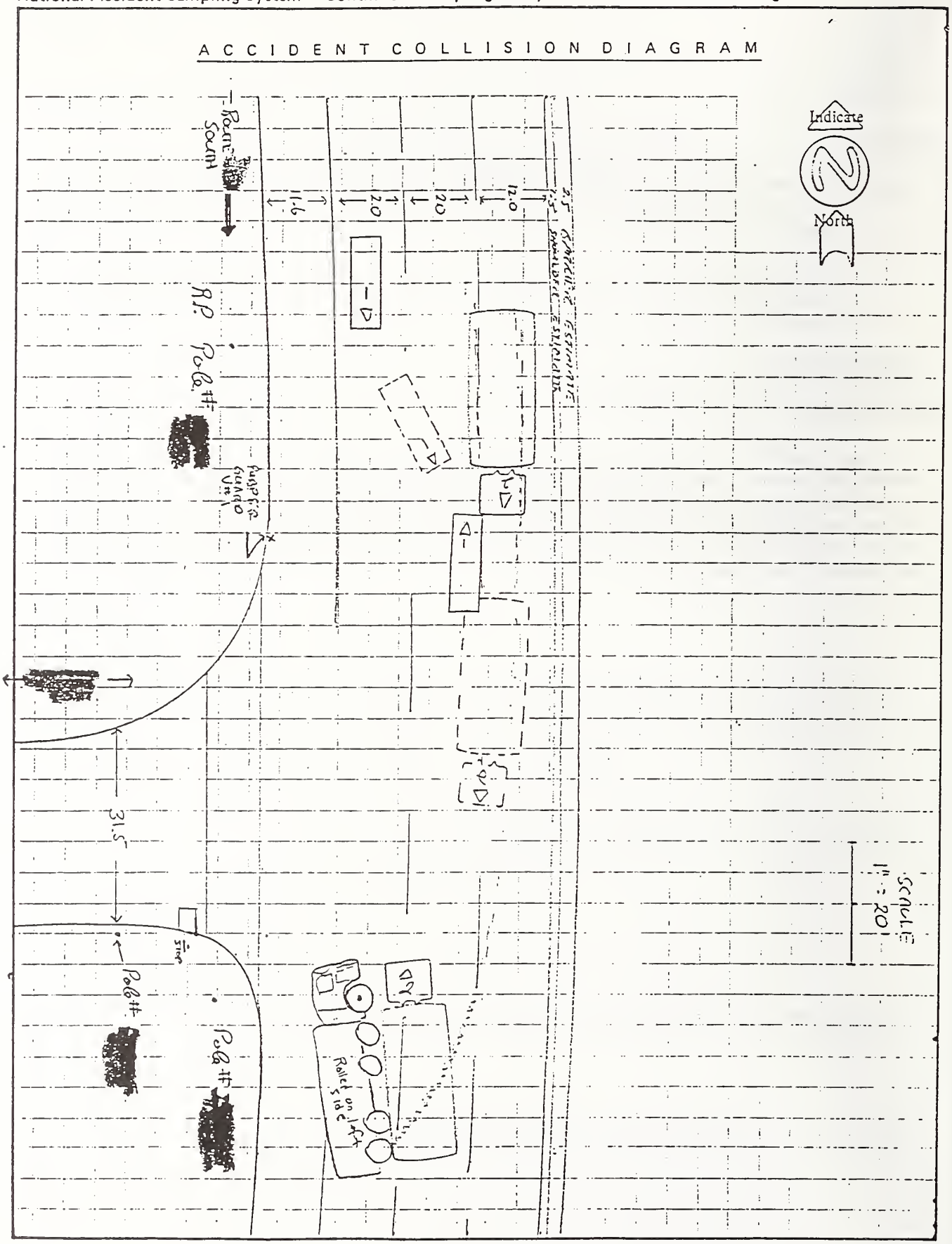
Right front passenger:Hospitalized (3 days). Fracture of right eye orbit AIS 2, Lacerated upper jaw, lower face AIS 1, lacerated knees AIS 1, concussion AIS 2, all sources unknown. Indications of contact with right A-pillar, door, and roofline.

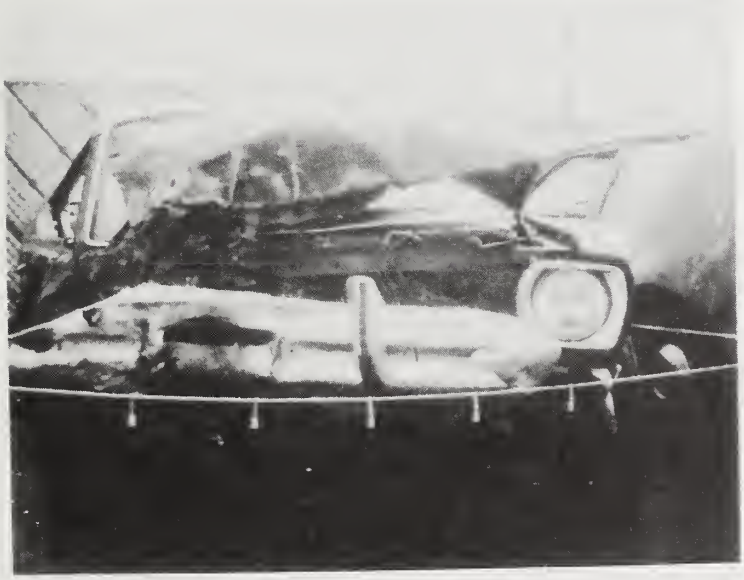
Vehicle 2: None

INJURY MITIGATION AND COMMENTS:

The damage location on the car indicates that the sheetmetal on the truck above the right front bumper must have engaged the car. However, the extent of damage (or lack thereof) indicates that the fender is very stiff in that region. Also, its clear from the way the truck's bumper has hinged around the frame attachment point that the stiff frame increases the aggressivity of the truck. The stiffness of both these regions should be reduced. Also, the amount of offset in the impact indicates that a device to deflect the car may have reduced the severities of the damage and injuries to occupants.

National Accident Sampling System — Continuous Sampling Subsystem: Accident Collision Diagram





YEAR: 1984
PSU: 54
CASENO: 96
NATWGT: 80.9

ACCIDENT DESCRIPTION:

Vehicle 1: '67 International 1200B pickup, GVW=73000 lbs, 1 occupant

Vehicle 2: '83 Freightliner COE w/trailer, GVW > 33000 lbs, 1 occupant

On a two lane roadway (speed limit 55 mph), vehicle 1 was heading north, encountered vehicle 2 (not described) which was trying to pass vehicle 3 while on the northbound side of the roadway. Vehicle 1 sideswiped vehicle 2 while trying to avoid it and collided with vehicle 3 in a full frontal mode.

OCCUPANTS:

Vehicle 1: Driver: unrestrained

Vehicle 2: Driver: no information available

DAMAGE:

Vehicle 1:
Location: Front
Direction of Force: Approximately 12 o'clock (355°)
Deformation: Extensive frontal damage, at bumper level 22" of crush and above grille 64" of crush. Frame was bent and the compartment integrity was lost through the windshield and both front doors.
Intrusions: Approximately 2-6" of frontal intrusion steering assembly and instrument panel.
Ejections: None
Contact locations: There was contact with the steering wheel and column, instrument panel, foot pedals, rear view mirror, etc.

Vehicle 3:
Location: Front
Direction of Force: Approximately 12 o'clock (350°).
Deformation: Minor damage to grill and bumper. Both headlights were broken.
Intrusion: None
Ejections: None
Contact locations: Driver contacted the knee panel.

ΔV:

Vehicle 1: 34.70 mph

Vehicle 2: Not calculated

Approach velocity = 38 mph

INJURIES:

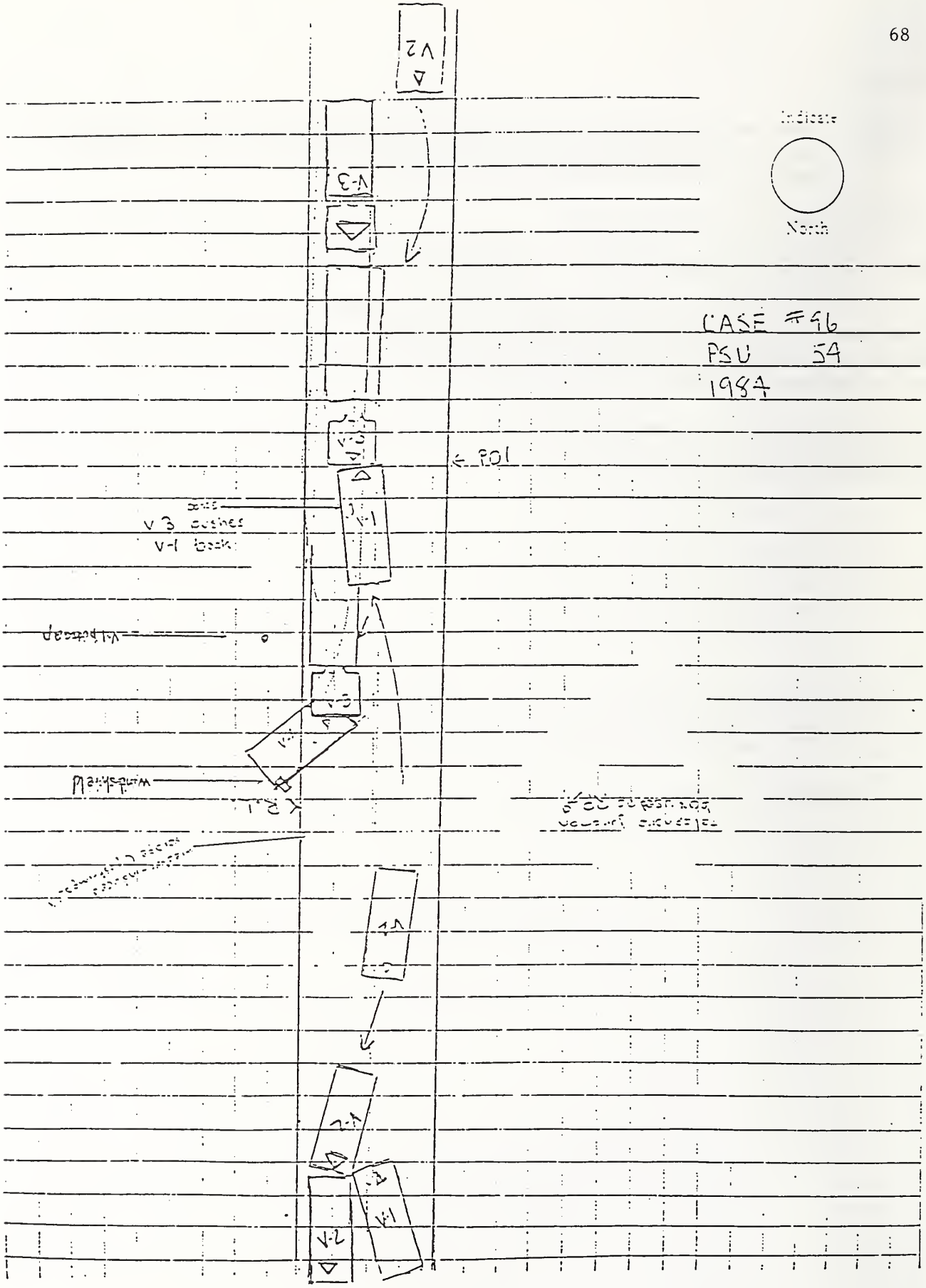
Vehicle 1: Driver sustained chest injury (e.g. collapsed lung, broken rib, lacerations (AIS 3) due to contact with steering assembly, face lacerations and fractured jaw (AIS 3) due to contact with steering assembly, and fractured knee (AIS 3) due to knee panel.

Vehicle 2: Driver sustained minor knee injury.

INJURY MITIGATION AND COMMENTS:

The damage to vehicle 1 can be attributed to the geometric mismatch between the two vehicles and the extremely stiff truck bumper. The geometric mismatch resulted in the light truck front end region above the grille to be pushed into the passenger compartment. This resulted in steering assembly and instrument panel intrusion. The unrestrained driver sustained injuries from contact with these surfaces.

The availability of a modified heavy truck bumper which is lower and softer would allow he lower front half o the car to absorb some of the energy along with the modified truck bumper. This would reduce the amount of intrusion and may mitigate the injuries sustained by the occupant.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CASE #96
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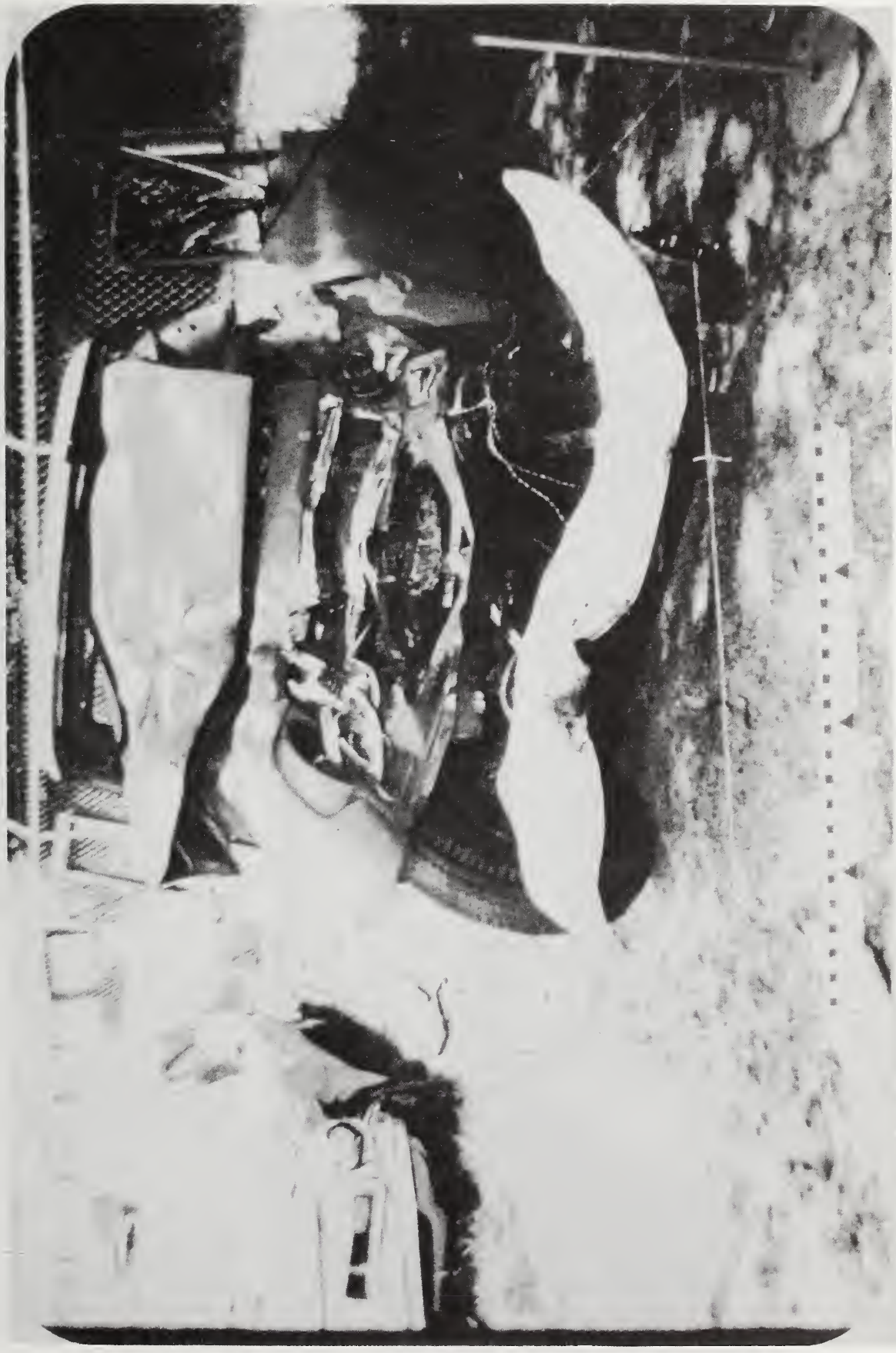
1984



YEAR: 1984
PSU: 12
CASENO: 035
NATWGT: 76.5

ACCIDENT DESCRIPTION:

Vehicle 1: '79 Pontiac Sunbird, 2 door hardtop sedan, 2700 lb_f, 1 occupant.

Vehicle 2: '84 Kenworth, COE high entry, 26400 lb_f, 1 occupant.

Impact Angle: 0 deg

Geometric Factor: 0.4

Override Factor: 0.5

Vehicle 1 crossed the centerline on a two lane road (speed limit 55 mph) and is struck head on by vehicle 2. The reason for Vehicle 2 crossing the centerline is unknown.

OCCUPANTS:

Vehicle 1: Driver: male, 21 yrs, 185 lb_f, lap+shoulder belt not used

Vehicle 2: Driver: male, 40 yrs, 185 lb_f, lap belt used.

DAMAGE:

Vehicle 1:
Location: Front
Direction of force: 12 clock direction
Deformation: Vehicle is completely demolished. The engine is found yards away from the vehicle.
Intrusion: Extensive
Ejections: Driver is ejected, medium unknown, windshield or left door suspected
Contact locations: Complete interior destruction. The steering wheel was bent and broken, upper torso contact suspected.
% Engaged: 100 % of front

Vehicle 2:
Location: Left front
Direction of force: 12 clock direction
Deformation: Left bumper (beyond frame attachment point) and fender torn away. Bumper dented from center to the left side, extensive damage to the axle and left front suspension and wheel. The left front wheel is twisted CCW and the cabin tilted to the left.
Intrusion: None
Ejections: None
Contact locations: None
% Engaged: 70 % of front engaged

ΔV:

Vehicle 1: 99.8 mph. (using momentum)

Vehicle 2: 10.2 mph. (,,)

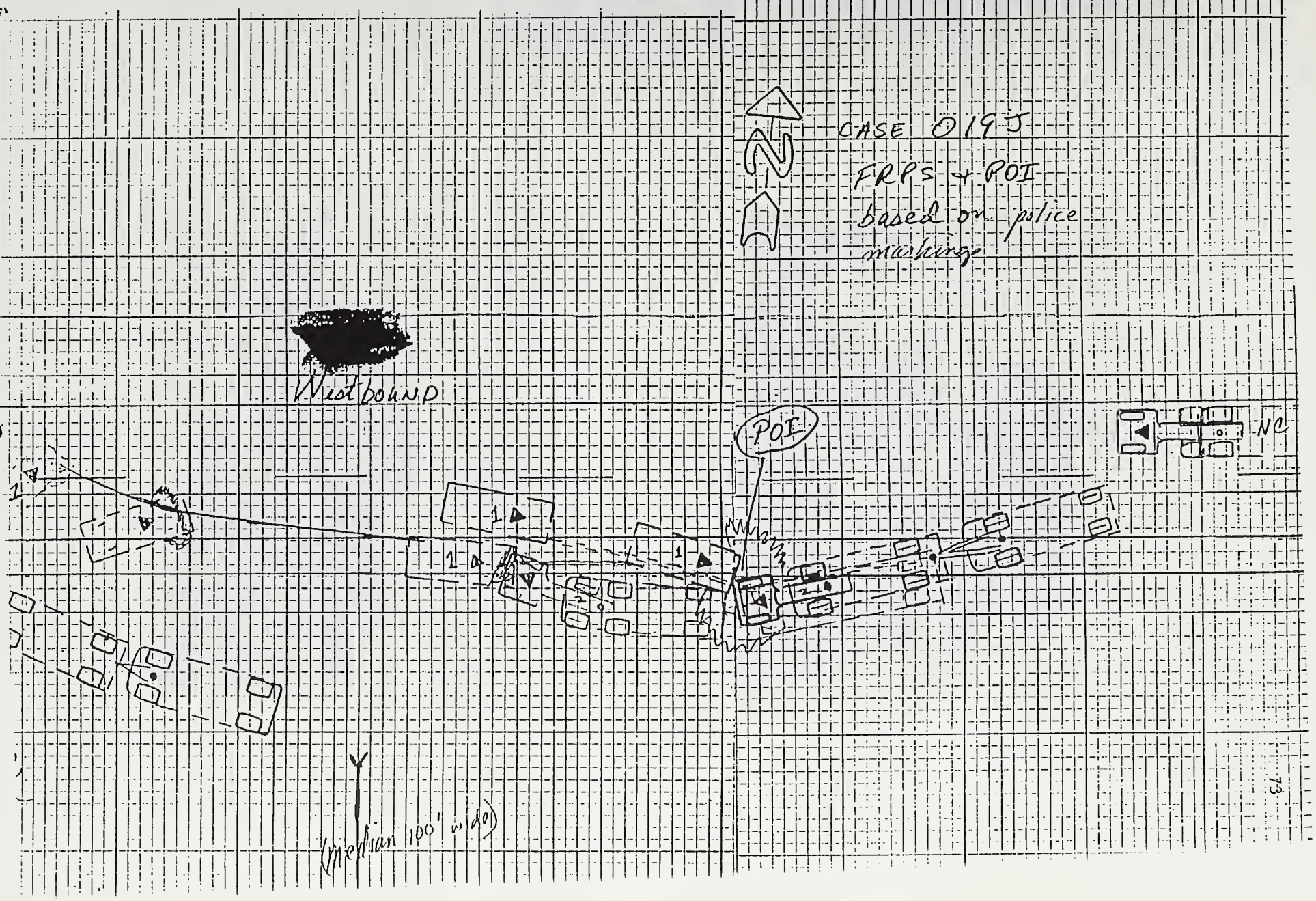
INJURIES:

Vehicle 1: Driver: Killed, multiple internal injuries, fracture of skull (brain exposed), neck, spine, legs, AIS 4

Vehicle 2: Driver: Transported and released. Multiple bumps and bruises, contusion to the right kidney due to seatback AIS 3, 12th right rib pulled away due to steering wheel AIS 1.

INJURY MITIGATION AND COMMENTS:

This was a very severe accident with very high delta-Vs. The integrity of the passenger car was completely lost. The driver was ejected and probably had extensive secondary impacts with the interior. The amount of intrusion was extensive. The truck had substantial damage to the front left side. The extensive damage to both vehicles suggests the high rates of speeds were involved making it impossible to address truck front-end modifications.


CASE 019 J
FRPs + POI
based on police markings
Westbound
POI
NC
Median 100' wide

FREIGHTLINER

YEAR: 1984
PSU: 82
CASENO: 019
NATWGT: 58.3

ACCIDENT DESCRIPTION:

Vehicle 1: '82 Chevrolet Monte Carlo, 2 door hardtop sedan, 3200 lb_f, 2 occupants

Vehicle 2: '83 Freightliner, COE truck pulling one trailer, 11362 lb_f, 1 occupant

Impact Angle: -30 deg

Geometric Factor: 0.6

Override Factor: 0.3

The right front side of the car strikes the right front of the truck. The outer 1/3rd of the car is involved in direct contact with the outer part of the truck bumper.

OCCUPANTS:

Vehicle 1: Driver: male, 21 yrs, weight unknown, lap+shoulder belt not used
Front right Passenger: female, 21 yrs, weight unknown, lap+shoulder belt not used

Vehicle 2: Driver: male, 36 yrs, 180 lb_f, lap belt not used.

DAMAGE:

Vehicle 1:
Location: Front
Direction of force: 12 clock direction
Deformation: Damage to the car is along the entire height of the front end (bumper to hood) and there is no evidence of override. There is a lateral shift of the front end to the right because of the narrow overlap area in the oblique collision. There was no integrity loss.
Intrusion: Front (steering column, dash) intrusion of greater than 15 cams.
Ejections: None
Contact locations: steering column, driver side visor and windshield, bottom dash (fusebox, radio, ash tray) dented in, right A-pillar, right door panel, right roofline.
% Engaged: 40 % of front

Vehicle 2:
Location: Front
Direction of force: 1 clock direction
Deformation: The right corner (beyond frame support point) pushed back, lower rim of the right fender is bent, right wheel-well cover is bent back.
Intrusion: None
Ejections: None
Contact locations: None
% Engaged: 70 % of front

ΔV:

Vehicle 1: 69.2 mph.

Vehicle 2: 19.4 mph.

INJURIES:

Vehicle 1: Driver: Transported and released, concussion AIS 2, fractured teeth AIS 1, laceration of both knees AIS 1, lacerated right hand, all sources unknown.

Front passenger:Hospitalized (3 days), fracture of right eye orbit AIS 2, laceration of lower face, legs AIS 1, concussion AIS 2, contusion of right face AIS 1.

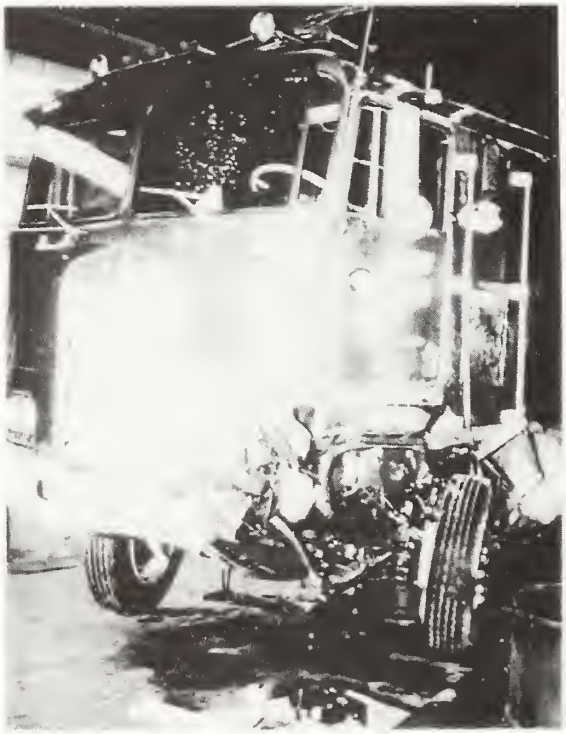
Vehicle 2: None

INJURY MITIGATION AND COMMENTS:

Sheet metal above the bumper of the truck must have engaged the car (based on the height of damage to the car. Lack of damage to this area indicates that the sheet-metal above the truck fender is very stiff. A reduction of this stiffness, and that of the bumper would help distribute the crash loads more uniformly. The truck frame is involved in the impact and does not absorb any energy (from the bending of the outer bumper about the frame support).

The entire front end of both vehicles have sustained direct damage. Any deflecting structure on the truck's front end may in fact add to the severity by providing less area to distribute the impact load.

North
77



YEAR: 1984
PSU: 76
CASENO: 029
NATWGT: 55.7

ACCIDENT DESCRIPTION:

Vehicle 1: '79 Toyota Longbed Pickup, 2415 lb_f, 1 occupant.

Vehicle 2: '83 International CBE, 28800 lb_f, 1 occupant.

Impact Angle: -70 deg

Geometric Factor: 0.0

Override Factor: 0.2

Vehicle 1 crosses center-line in trying to pass a non-contact vehicle on a two lane road (speed limit 55 mph). Vehicle 2 is oncoming in that lane. Vehicle 1 starts skidding, rotates, strikes a bridge rail with front, is redirected to strike left rear on the guardrail, bounces into the path of vehicle 2 and is hit on the front left corner. Damage to the Vehicle 2 front left is partly caused by hitting the guard-rail.

OCCUPANTS:

Vehicle 1: Driver, male, 36 yrs, 140 lb_f, lap+shoulder belt not used.

Vehicle 2: Driver, male, 29 yrs, 150 lb_f, lap belt used.

DAMAGE:

Vehicle 1:
- Location: Front left corner
- Direction of force: 10 clock direction
- Deformation: Front corner crushed in, no evidence of override, crush extends along the entire height of the front, some shift of the front to the right.
- Intrusion: None
- Ejections: None
- Contact locations: Driver door panel, upper steering wheel rim, lower left dash, foot pedals, gear shift, lower center dash radio, right windshield webbed, right door panel.
- % Engaged: 20 % of front corner

Vehicle 2:
- Location: Front
- Direction of force: 12 clock direction
- Deformation: Entire front bumper is dented, right fender is ripped off and right outer bumper severely bent, right wheel has paint transfer.
- Intrusion: None
- Ejections: None
- Contact locations: None
- % Engaged: 30 % of front right corner

ΔV:

Vehicle 1: 50.7 mph (using momentum, assuming truck speed=55, car speed=0)

Vehicle 2: -4.2 mph (,,)

INJURIES:

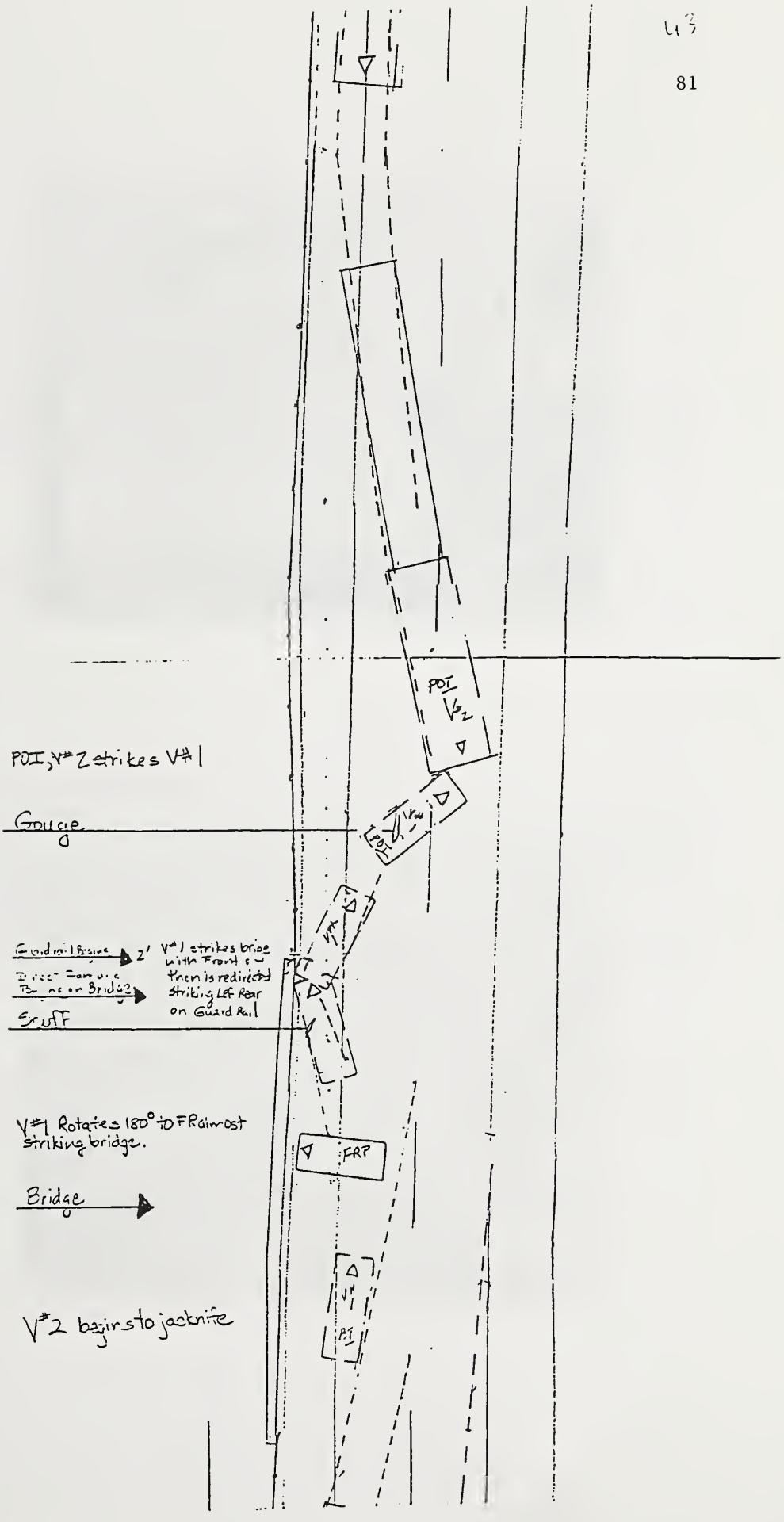
Vehicle 1: Driver, hospitalized (3 days), concussion AIS 2, left face contusions AIS 1, upper facial lacerations AIS 1, all due to windshield, left elbow contusion AIS 1, right wrist contusion AIS 1, contusion of the back of the head AIS 1, all sources unknown.

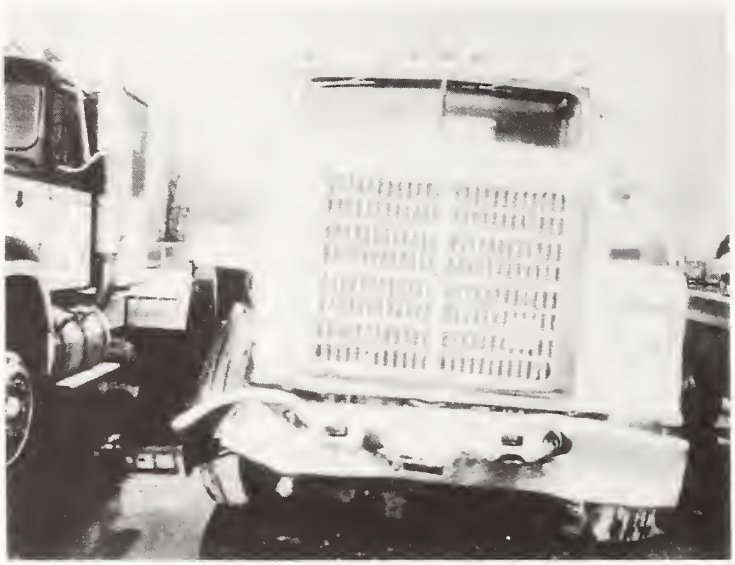
Vehicle 2: None

INJURY MITIGATION AND COMMENTS:

It is difficult to determine the damage on vehicle 1 caused by impact with vehicle 2 because vehicle 1 was involved in collisions with the bridge guard-rail prior to hitting vehicle 2. However, there seems to be complete engagement of the heavy truck's bumper and the pickup's front-end. However, there is little deformation of the heavy truck bumper around the points of attachment to the truck frame. Decreasing the stiffness of the truck bumper should result in less severe crash pulse for the pickup. The injuries to the driver of the pick-up are caused by delta-V alone (no intrusion). However, contact points on the right side of the pick-up cab indicates occupant interior impacts caused by previous delta-Vs due to guard-rail impacts. The specific injuries caused by the collision with the heavy truck is therefore not very obvious.

The apparent direct damage to the truck's entire front end suggests that a deflecting structure may reduce the area over which the impact load is distributed, resulting in a more severe impact to vehicle 1.


POI, V#2 strikes V#1
Guardrail
Guardrail Broken
Fence Damage
Trees on Bridge
Earth
V#1 strikes bridge with Front & then is redirected striking Left Rear on Guard Rail
V#1 Rotates 180° to Rainmost striking bridge.
Bridge
V#2 begins to jackknife
POI
V#2
V#1
FRP



YEAR: 1985
PSU: 11
CASENO: 133
NATWGT: 103.6

ACCIDENT DESCRIPTION:

Vehicle 1: '78 Ford LTD, 4 door sedan, CW=4079 lbs, 2 occupants

Vehicle 2: '82 Ford F900 CBE, single unit straight truck, GVW=28000 lbs, 1 occupant

On a two lane roadway, vehicle 1 heading east crossed over the centerline and into the entire lane of west bound traffic. Vehicle 2 steering left tried to avoid oncoming vehicle 1 but was unable to avoid it. Vehicle 1 hit vehicle 2 in a full frontal mode. Vehicle 1 was propelled backwards approximately 50 ft coming to rest in the east bound lane facing east.

OCCUPANTS:

Vehicle 1: Driver: male, 66 yrs, unrestrained, entrapped in vehicle
Passenger: female, 63 yrs, restrained (lap and should belt)

Vehicle 2: Driver: male

DAMAGE:

Vehicle 1:
Location: Front
Direction of Force: Approximately 12 o'clock (350°)
Deformation: Entire front of vehicle was demolished (average crush 81"). No evident of override. A pillar, roof and side rail buckled, steering column became disengaged, instrument panel destroyed.
Intrusion: >12" through steering assembly, entire instrument rails, A and B pillars, door panels, roof, side rails, and windshield header.
Ejections: Driver ejected through windshield.
Contact locations: There was contact with the windshield, steering assembly, instrument panel, roof side rail, windshield header, A and B pillars, etc.

Vehicle 2:
Location: Front
Direction of Force: Approximately 12 o'clock (350°)
Deformation: Truck sustained frontal damage with fender and bumper being torn off. Compartment integrity was lost through the windshield.
Intrusion: None
Ejections: None
Contact locations: There was contact with the windshield, steering wheel, and knee panel.

ΔV:

Vehicle 1: 50.0 mph

Vehicle 2: Not calculated
Approach velocity = 57.0 mph

INJURIES:

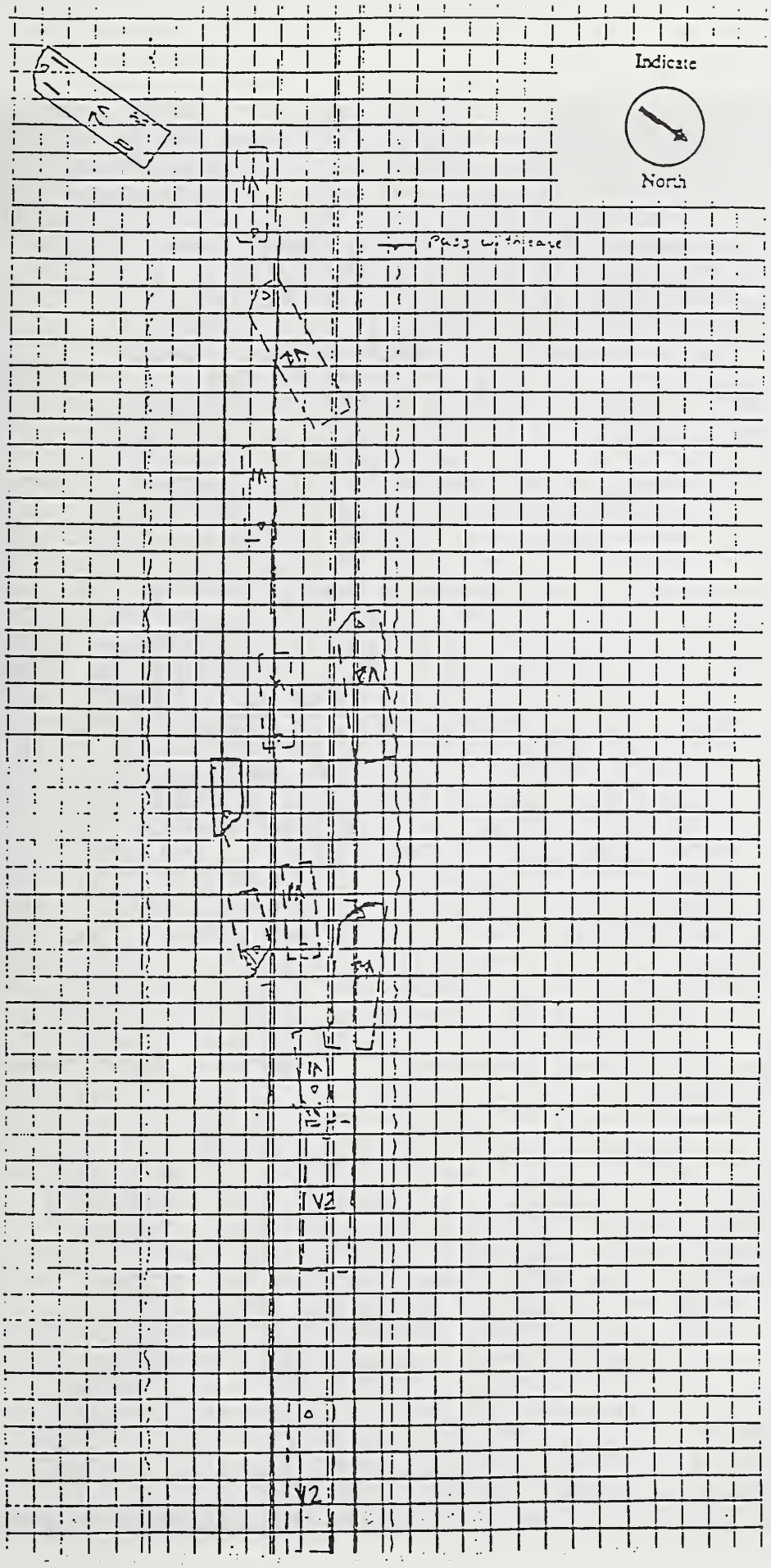
Vehicle 1: Both drive and passenger were killed. Driver was killed to multiple fractures of head and chest (all chest bones crushed) due to steering wheel hub and rim contact. legs and arms were also fractured. passenger died from a fractured neck due to contact with windshield header.

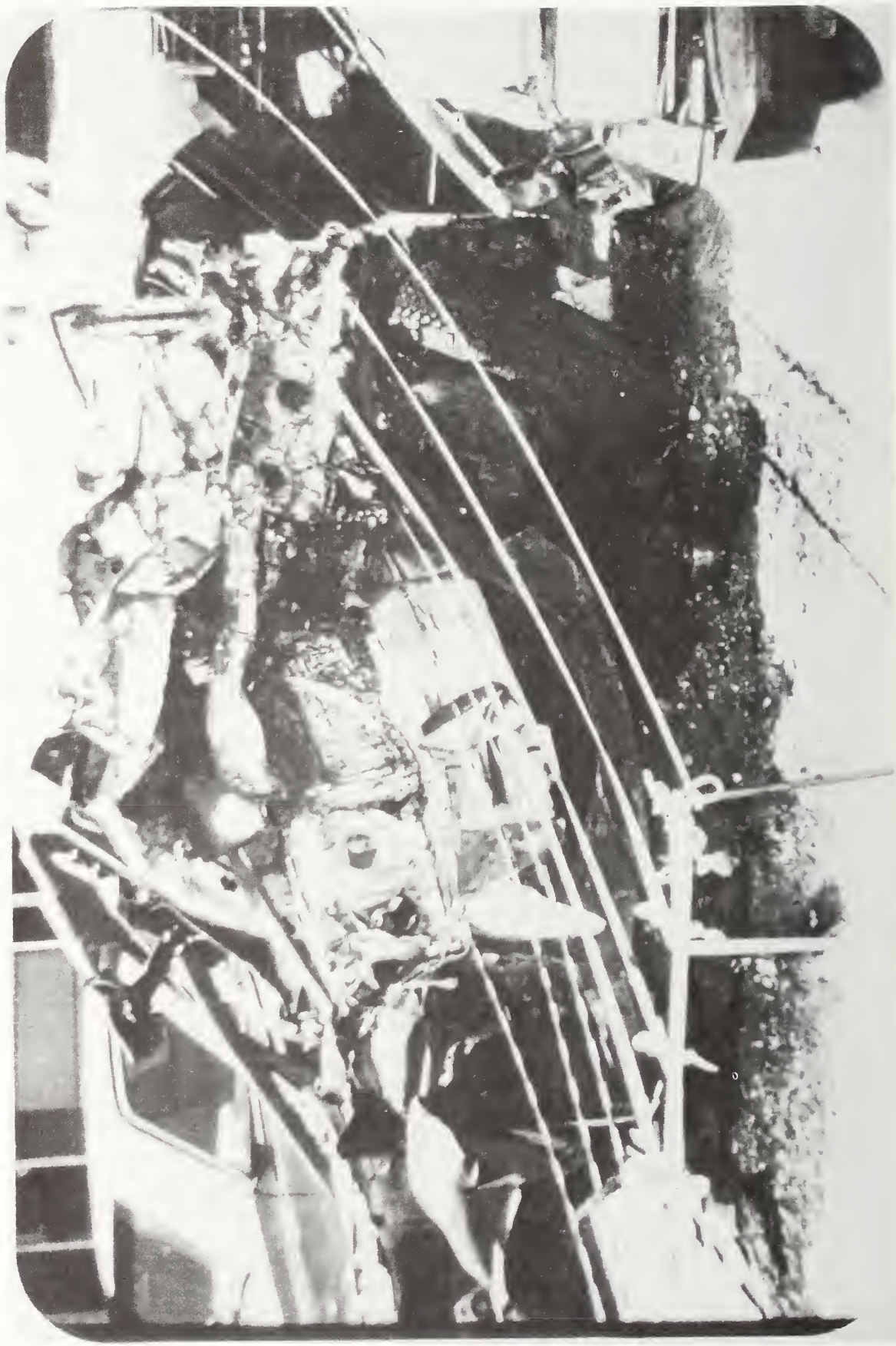
Vehicle 2: Driver sustained left knee sprain due to contact with knee panel, nose, left hand and elbow abrasions due to contact with steering wheel and windshield.

INJURY MITIGATION AND COMMENTS:

Due to the severity of the damage and the large delta-v calculated, a modified truck bumper would not be of benefit here.

CASE #13
PSU 1
1985





YEAR: 1985
PSU: 79
CASENO: 78
NATWGT: 19.9

ACCIDENT DESCRIPTION:

Vehicle 1: '75 Ford F250 Pickup, 3424 lb_f, One occupant

Vehicle 2: '85 Mack CBE tanker, 14240 lb_f, one occupant

Impact Angle: 0 deg

Geometric Factor: 0.7

Override Factor: 0.0

Vehicle 1 crossed the centerline of a 2 lane road (speed limit 50 mph) and hit Vehicle 2 headon. Vehicle 1 caught fire and the occupant was incinerated.

OCCUPANTS:

Vehicle 1: Driver, male 54 yrs, restraint usage unknown.

Vehicle 2: Driver, male, 31 yrs, lap belt used.

DAMAGE:

Vehicle 1:
Location: Front
Direction of force: 12 o'clock
Deformation: The vehicle front was demolished (crush of 75 inches). There was considerable lateral shift of the engine compartment to the right. There was no evidence of override of the pickup by the truck. The engine block was shattered. The vehicle was incinerated.
Intrusion: Severe. The entire front (dash, steering column) was pushed into the driver seat.
Ejections: None
Contact locations: Unknown. Interior was destroyed by fire.
% Engaged: 90 % of front

Vehicle 2:
Location: Front
Direction of force: 12 o'clock
Deformation: The entire width of the front bumper was damaged (max crush of 19 inches). The fenders and wheel covers were torn off on both sides. The center lower grill was dented.
Intrusion: None
Ejections: None
Contact locations: Steering wheel, ignition key
% Engaged: 100 % of front

ΔV:

Vehicle 1: 88.7 mph (based on momentum and 55 mph speeds)

Vehicle 2: 21.3 mph

INJURIES:

Vehicle 1: Driver, DOA, crushed skull, transection at neck, incineration of whole body AIS 6, fractured L&R femur, lower jaw AIS 3, fractured ribs AIS 4, sternum AIS 2

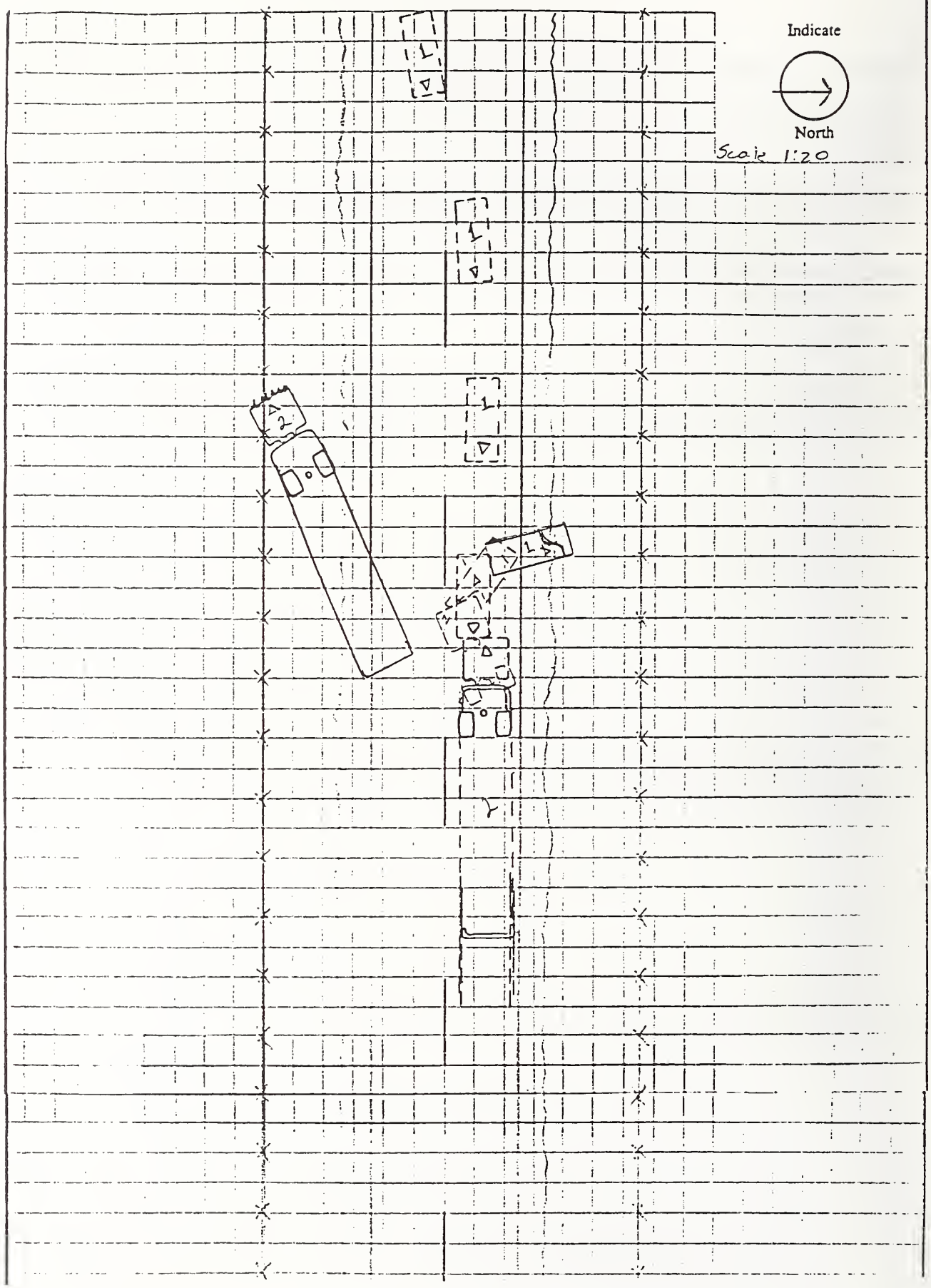
Vehicle 2: Driver, lacerated forehead, R knee, abrasions L forearm, hand, both knees, contusions L forearm, both knees, AIS 1

INJURY MITIGATION AND COMMENTS:

This impact condition was too severe. There was more than the usual damage to the truck bumper and suspension. The pickup had no override and engaged the truck with most of its front with. Also, the accident diagram indicates that the pickup rotated into the path of the truck. Therefore, this case is judged to be not addressable.

Case Number 0781

ACCIDENT COLLISION DIAGRAM



Delete Street Names After Case Review

MACK

YEAR: 1985
PSU: 38
CASENO: 227
NATWGT: 38.1

ACCIDENT DESCRIPTION:

Vehicle 1: '80 Mercury Capri, 3-door hatchback, 2600 lb_f, 1 occupant.

Vehicle 2: '85 International Harvester 1900 single unit truck, 2 occupants. (This vehicle appears to have a hydraulic structure welded to the front bumper).

Impact Angle: 30 degrees

Geometric Factor: 0.5

Override Factor: 0.5

Vehicle 1, heading west on a two lane road (speed limit 35 mph), crosses centerline and strikes oncoming vehicle 2 head on. Travel speeds are unknown.

OCCUPANTS:

Vehicle 1: Driver, male, 23 yrs, 154 lb_f, manual lap+shoulder belt not used.

Vehicle 2: Driver, male, 37 yrs, 256 lb_f, manual lap belt not used.
Right front passenger, male, 40 yrs, 256 lb_f, manual lap belt not used.

DAMAGE:

Vehicle 1:
Location: Front end extending into passenger compartment
Direction of force: 12 o'clock direction
Deformation: Extensive damage to front end and passenger compartment. Engine hood torn away. Both A-pillars pushed rearward. Passenger compartment roof is buckled. Front wheels and axle pushed rearward. Passenger and driver doors pushed rearward. Instrument panel pushed rearward. Integrity loss through all passenger compartment windows and driver door.
Intrusion: Intrusion to passenger compartment floor and instrument panel greater than 15 cm.
Ejection: None
% engaged: 100%

Vehicle 2:
Location: Front end of vehicle
Direction of force: 12 o'clock direction
Deformation: Direct damage to entire lower front end. Front bumper scratched and dented. Both corners of bumper pushed rearward. Hydraulic structure attached to bumper is scratched and dented.
Intrusion: No intrusion
Ejection: None.
% Engaged: 100%

ΔV:

Vehicle 1: 49.3 mph. (assuming mass of truck is 15,000 lb_f)

Vehicle 2: 8.5 mph. (,,)

INJURIES:

Vehicle 1: Driver: fatal injuries.

Vehicle 2: Driver: contusion on right and left knees - ais 1, abrasions on left knee - ais 1, strained neck - ais 1.
Right front passenger: abrasions on right lower leg - ais 1, abrasions on left arm -ais 1.

INJURY MITIGATION AND COMMENTS:

The discrepancy between the damage extent of each vehicle indicates a large difference between the vehicle's stiffness. The hydraulic structure attached to the truck's front bumper presumably is responsible for much of the difference.

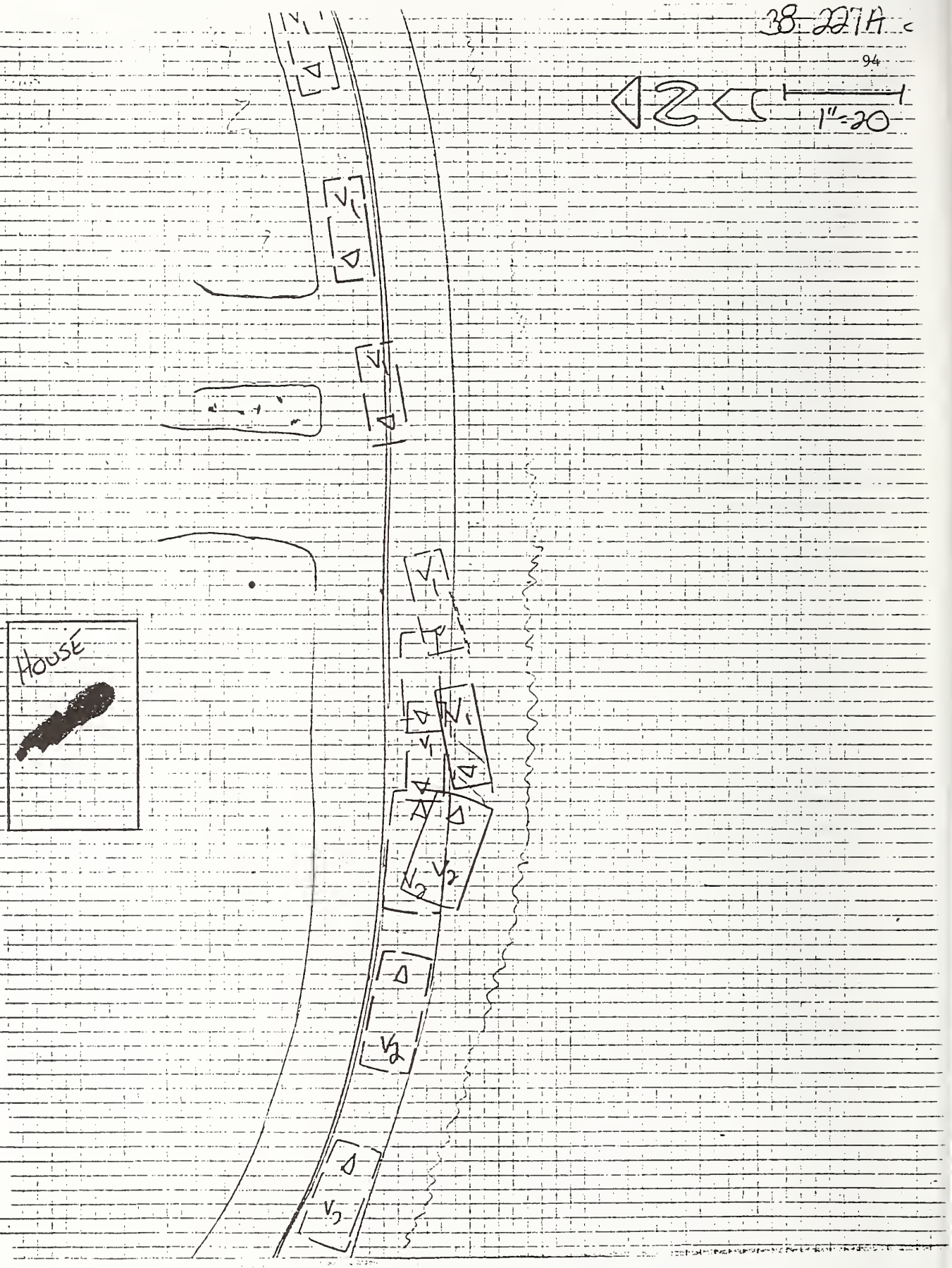
There does not appear to be much evidence of truck override in this case. The hydraulic structure extended below the truck's bumper and provided a better geometric match.

It is impossible to address the concept of a deflecting structure on the truck's front end in this case because of the existing hydraulic structure.

38-227A

94

1"=20



YEAR: 1985
PSU: 12
CASENO: 56
NATWGT: 92.2

ACCIDENT DESCRIPTION:

Vehicle 1: '81 Chevrolet Caprice, 4-door sedan hardtop, 3600 lb_f, 1 occupant.

Vehicle 2: '77 medium/heavy Peterbilt truck pulling one trailer, COE, 62800 lb_f 1 occupant.

Impact Angle: 10 degrees

Geometric Factor: 0.0

Override Factor: 0.2

Vehicle 1, heading west on a two lane road (speed limit 55 mph), crosses centerline and into path of oncoming vehicle 2. Front left corner of vehicle 1 strikes front left corner of vehicle 2. Vehicle 1 spins counterclockwise out of path of vehicle 2 and comes to rest in shoulder. Travel speeds are unknown.

OCCUPANTS:

Vehicle 1: Driver, male, 41 yrs, 160 lb_f, manual lap+shoulder belt not used.

Vehicle 2: Driver, male, 55 yrs, 172 lb_f, manual lap belt used.

DAMAGE:

Vehicle 1:
Location: Front end extending into passenger compartment
Direction of force: 11 o'clock direction
Deformation: Extensive damage to front end and passenger compartment. Total destruction of left side of vehicle. Left A and B-pillars torn away from attachment points. Passenger compartment roof pushed back and downward. Rear end of vehicle pushed downward. Integrity loss through left side doors and roof.
Intrusion: Intrusion to side of passenger compartment greater than 15 cm.
Ejection: Through passenger compartment roof
% engaged: 100%

Vehicle 2:
Location: Front left corner of vehicle
Direction of force: 11 o'clock direction
Deformation: Direct damage to entire lower front end. Bumper pushed back and bent inward at both corners. Right front axle and wheel pushed back 60 inches. Left front tire pushed outward. Truck frame rails are bent. Front grill pushed inward and cracked. Part of engine cover above left corner bumper is missing.
Intrusion: No intrusion
Ejection: None.
% Engaged: 100%

ΔV:

Vehicle 1: Not calculated.

Vehicle 2: Not calculated.

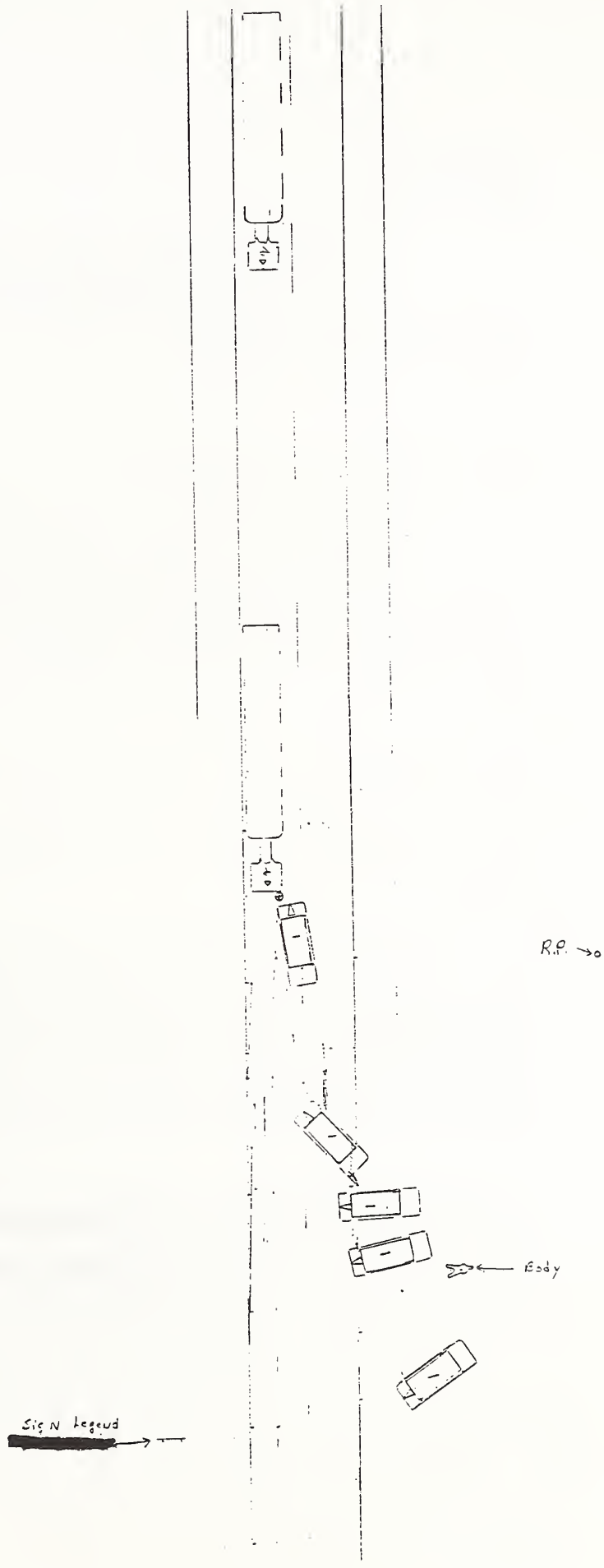
INJURIES:

Vehicle 1: Driver: fatal injuries, massive internal and external injuries - ais 7

Vehicle 2: Driver: contusion on left knee - ais 1, abrasions on left and right knees and left elbow - ais 1.

INJURY MITIGATION AND COMMENTS:

The impact in this case was very severe, indicating that high speeds of travel were involved. The extent of severity makes it impossible to fully address truck front end modifications that would likely reduce occupant injury and damage to the vehicle. However, from the damage evidence, it appears that truck override did occur. Lowering the truck's front end and providing for a better geometric match may reduce the impact severity in such cases. Also the geometry of the collision indicates that a deflecting truck bumper may reduce the impact severity on the car


R.P.
Body
Sign legend

YEAR: 1985
PSU: 12
CASENO: 21
NATWGT: 91.0

ACCIDENT DESCRIPTION:

Vehicle 1: '75 Plymouth Duster, 2-door sedan hardtop, 3050 lb_f, 1 occupant.

Vehicle 2: '72 International Harvester, medium/heavy truck pulling one trailer, COE, 30,100 lb_f, 1 occupant.

Impact Angle: 45 degrees

Geometric Factor: 0.90

Override Factor: 0.5

Vehicle 1, heading west on a two lane road (speed limit 55 mph), crosses centerline and into path of oncoming vehicle 2. Right front corner bumper of vehicle 1 strikes front center of vehicle 2. Travel speeds are unknown.

OCCUPANTS:

Vehicle 1: Driver, male, 18 yrs, 145 lb_f, manual lap+shoulder belt not used.

Vehicle 2: Driver, male, 43 yrs, 205 lb_f, manual lap belt not used.

DAMAGE:

Vehicle 1:
Location: Front end extending into passenger compartment
Direction of force: 1 o'clock direction
Deformation: Extensive damage to front end and passenger compartment. Front bumper and engine hood torn away. Right A and B-pillars torn from attachment points. Passenger compartment roof pushed back and downward. Right front wheel rim is bent. Integrity loss through all passenger compartment windows and both doors. Rear end of car shifted upwards.
Intrusion: Intrusion to passenger compartment floor and right side greater than 15 cm.
Ejection: None
% engaged: 95%

Vehicle 2:
Location: Front of vehicle
Direction of force: 11 o'clock direction
Deformation: Direct damage to entire lower front end. Right front axle is bent back with right front tire resting against gas tank. Front grill pushed inward and cracked. Part of engine cover above bumper is missing.
Intrusion: No intrusion
Ejection: None.
% Engaged: 100%

ΔV:

Vehicle 1: Not calculated.

Vehicle 2: Not calculated.

INJURIES:

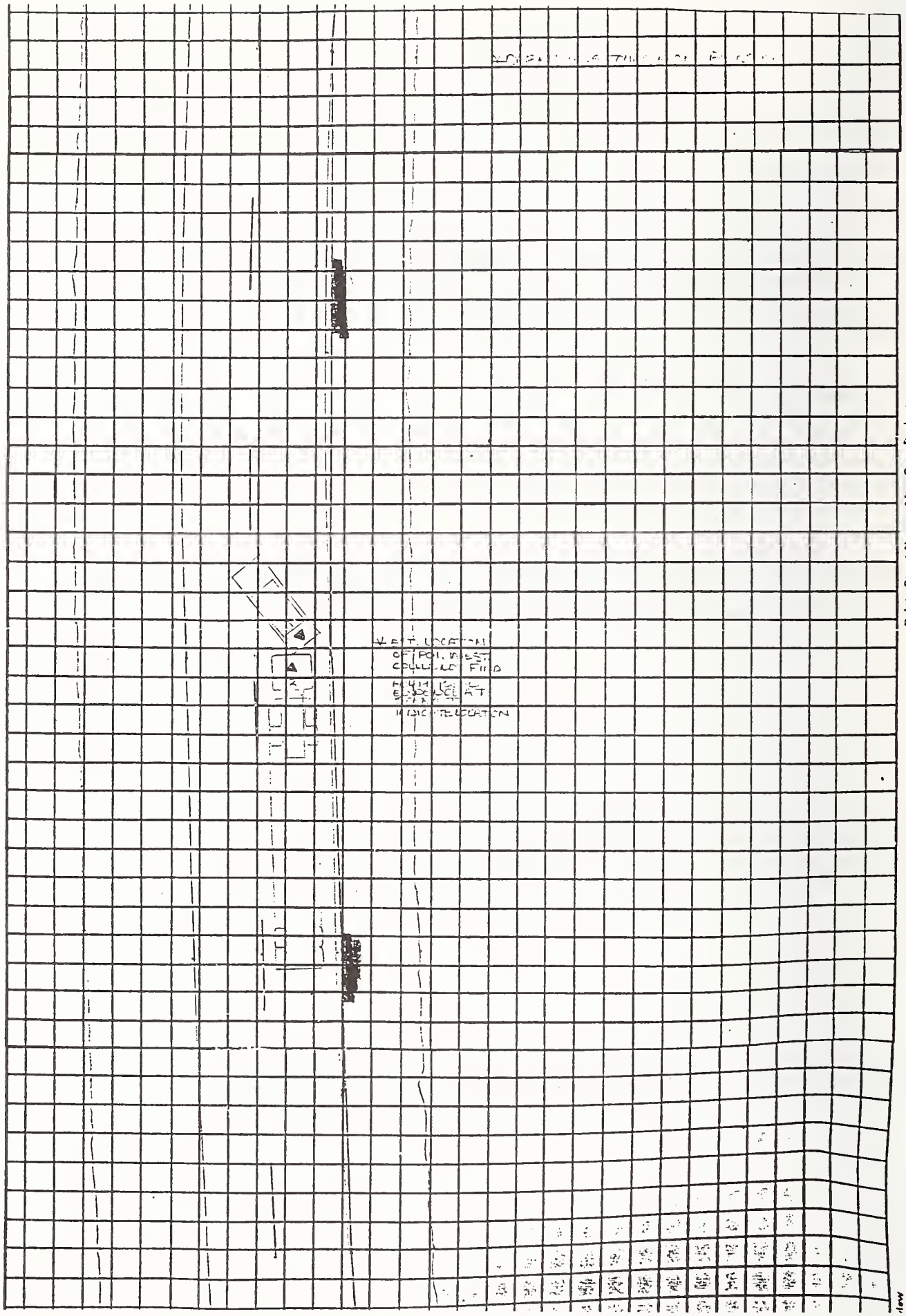
Vehicle 1: Driver: fatality, crushed chest - ais 6, fractured skull - ais 2, multiple leg fractures - ais 2, cerebral hemorrhage - ais 7.

Vehicle 2: Driver: contusion on left elbow - ais 1.

INJURY MITIGATION AND COMMENTS:

The impact in this case was very severe, indicating that high speeds of travel were involved. From the damage evidence (the shape of the passenger compartment), it appears that truck override did occur. Lowering the front end of the truck for a better geometric match would most likely reduce the severity of impact. Because of the damage severity however, it does not appear that softening the truck's front end would have made a significant difference

From the impact angles and location, it does not appear that a deflecting structure on the truck's front end would have reduced the crush. The passenger car appears to have rotated into the path of the truck after impact. A deflecting structure with a reduced frontal area, therefor, may add to the damage severity.



Delete Street Names After Case Review

YEAR: 1985
PSU: 11
CASENO: 275
NATWGT: 45.0

ACCIDENT DESCRIPTION:

Vehicle 1: '82 Pontiac Firebird, 2-door sedan hardtop, 3000 lb_f, 1 occupant.

Vehicle 2: '73 Ford CT 8000 medium/heavy single unit truck, COE, 27,600 lb_f, 1 occupant. (This vehicle had hydraulic lifting structures attached to the front bumper)

Impact Angle: 30 degrees

Geometric Factor: 0.0

Override Factor: 0.5

Vehicle 1, heading east on a four lane road (speed limit 35 mph), enters a right sweeping curve and crosses the centerline into the path of oncoming vehicle 2. Front right corner of vehicle 1 strikes front left corner of vehicle 2. Vehicle 1 spins counter-clockwise out of path of vehicle 2 and comes to rest in westbound lanes. Travel speeds are unknown.

OCCUPANTS:

Vehicle 1: Driver, male, 21 yrs, 165 lb_f, manual lap+shoulder belt used.

Vehicle 2: Driver, male, 43 yrs, 188 lb_f, no restraint system available.

DAMAGE:

Vehicle 1:
Location: Front end
Direction of force: 1 o'clock direction
Deformation: Extensive damage to front end. Maximum crush at right bumper corner. Right front wheel bent and displaced. Left front wheel displaced. Right A-pillar bent backward. Right passenger door latch failed. Right rear wheel and axle separated from transaxle. Bent frame and endshift. Integrity loss through passenger door.
Intrusion: Intrusion of instrument panel greater than 15 cm.
Ejection: None
% engaged: 100%

Vehicle 2:
Location: Front left half of vehicle
Direction of force: 11 o'clock direction
Deformation: Front bumper bent downward. Hydraulic arm displaced. Left front wheel displaced 1" back. Truck frame bent downward. Sheet metal above bumper scratched and dented.
Intrusion: No intrusion
Ejection: None.
% Engaged: 50%

ΔV:

Vehicle 1: 68.3 mph.

Vehicle 2: 5.1 mph.

INJURIES:

Vehicle 1: Driver: internal head injuries - ais 4, upper and middle facial lacerations - ais 1.

Vehicle 2: Driver: muscle strain in neck - ais 1, laceration on left wrist - ais 1, contusion on left wrist - ais 1, laceration on right knee - ais 1.

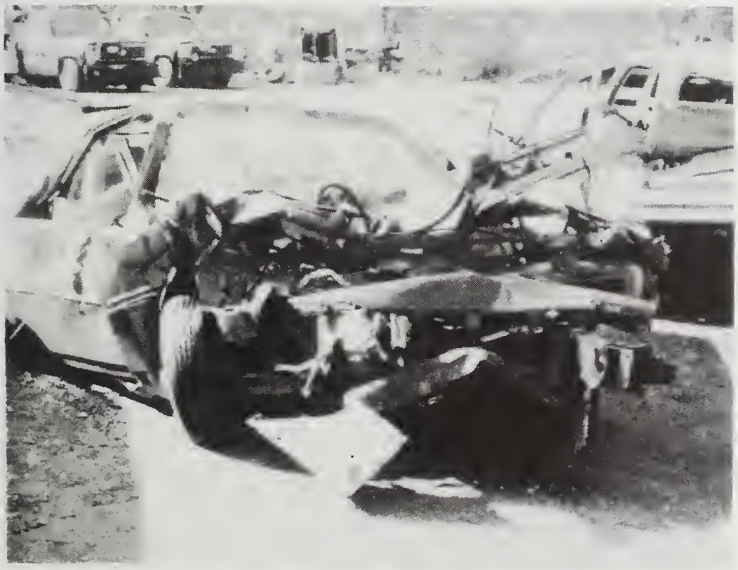
INJURY MITIGATION AND COMMENTS:

The passenger car sustained heavy damage while the truck appears to have sustained very little damage. This indicates a large difference between the stiffness of each vehicle. Softening the truck front should decrease the damage severity to the passenger car. It should be noted however, that the hydraulic lifting arms on the truck front presumably added to the severity in this case and may override the effects of a softer front end.

There does not appear much evidence of truck override. The hydraulic arms extended below the truck bumper and provided a better geometric match.

Due the angle at which the passenger car struck the truck, a deflecting structure on the truck's front end may reduce the damage severity as well.

Delete Street Names After Case Review
Delete Street Names After Case Review
Fluid Spill
Barrier Curb
Square Drain R.P.
* See revised



YEAR: 1985
PSU: 29
CASENO: 105
NATWGT: 102.5

ACCIDENT DESCRIPTION:

Vehicle 1: '75 Dodge Dart, 4 door sedan, CW=3285 lbs, 2 occupants

Vehicle 2: '83 Freightliner COE w/trailer, GVW=48000 lbs, 1 occupant

On a two lane road (one way), vehicle 1 was travelling north in the right lane and vehicle 2 was travelling in the left lane. Vehicle 2 steered right to change lanes and hit vehicle 1 on the left side (rear half) causing vehicle 1 to rotate counterclockwise in front of vehicle 2 resulting in contact. The left front region of the dart impacted the left front corner of the truck.

OCCUPANTS:

Vehicle 1: Driver: female, 60 yrs, 126 lbs, restrained (lap and should belt)
Passenger: no information available

Vehicle 2: Driver: unrestrained

DAMAGE:

Vehicle 1:
Location: Front
Direction of Force: 12 o'clock
Deformation: The left front region of vehicle 1 sustained minor damage (approximately 11" of crush) and the left side also sustained minor damage (approximately 2"). compartment integrity was not lost.
Intrusion: None
Ejections: None
Contact locations: Windshield, steering wheel (rim/hub/spoke), left, center, and right instrument panel and below.

Vehicle 2:
Location: Front
Direction of Force: 12 o'clock
Deformation: Minor damage to truck. Compartment integrity was lost through the windshield.
Intrusion: None
Ejections: None
Contact locations: None

ΔV:

Vehicle 1: Not calculated

Vehicle 2: Not calculated

Approach velocity = Not calculated

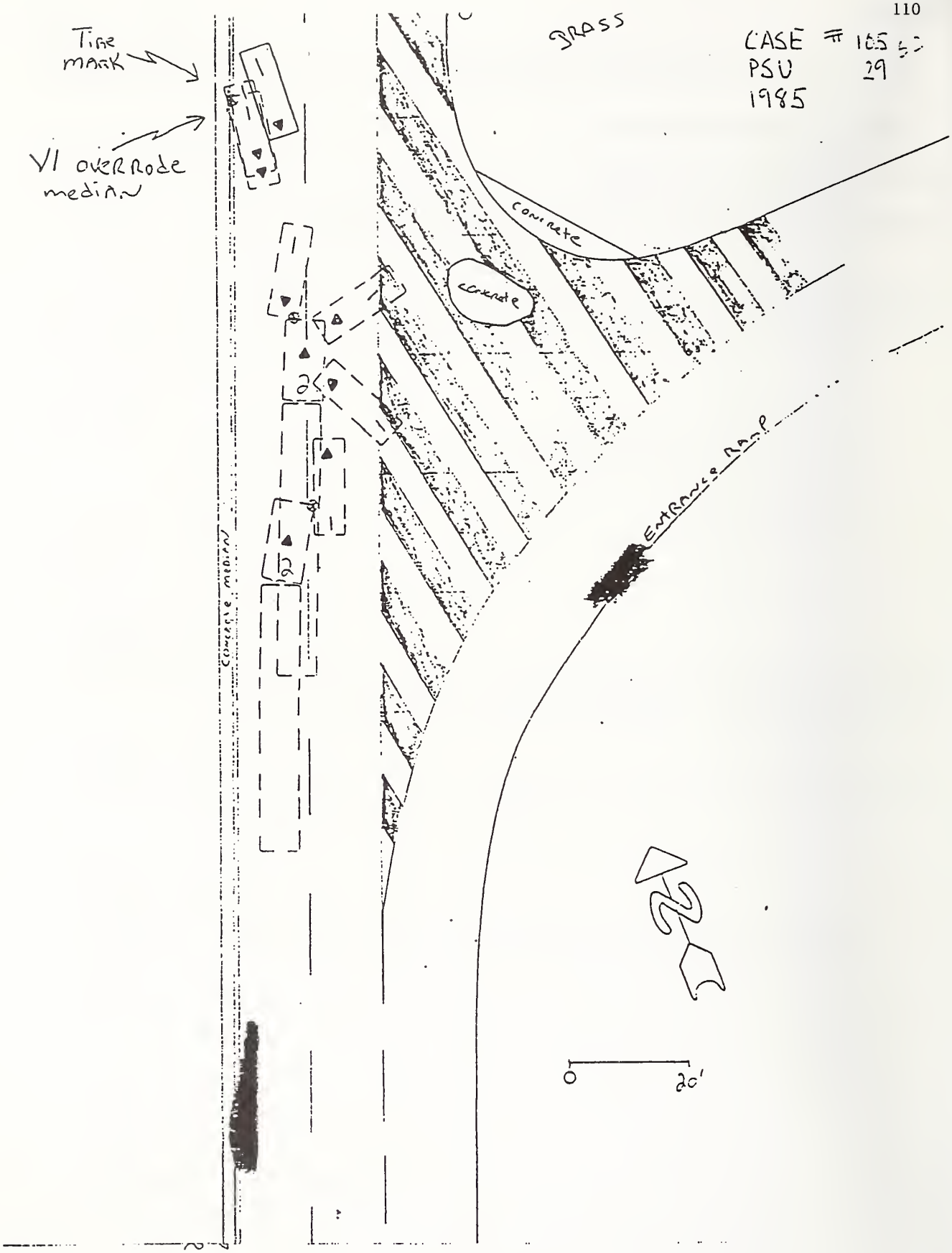
INJURIES:

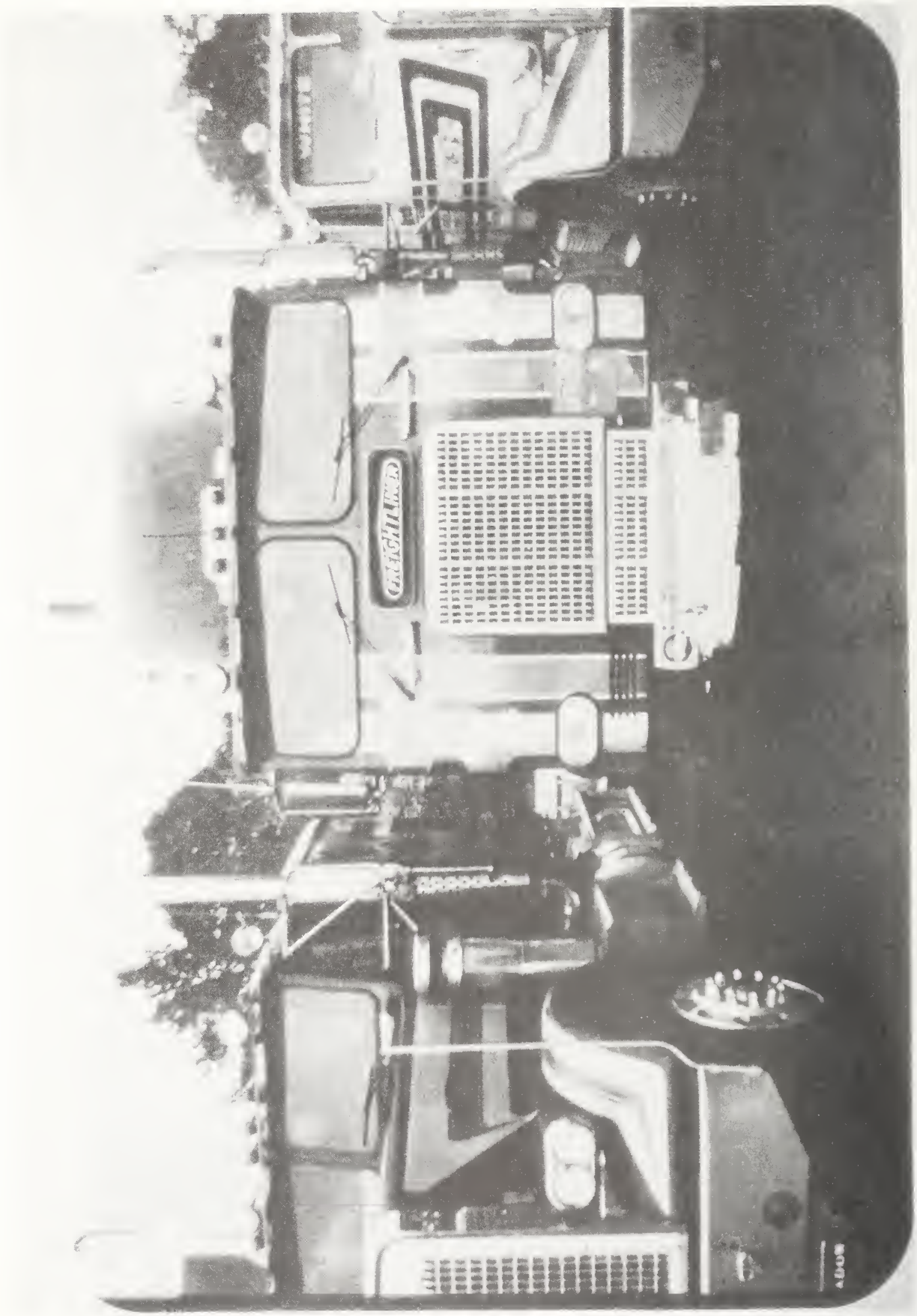
Vehicle 1: Driver sustained left upper and lower leg contusions (AIS 1) due to contact with door hardware or armrest. Passenger sustained AIS 2 injuries.

Vehicle 2: Driver sustained no injuries.

INJURY MITIGATION AND COMMENTS:

A modified truck bumper may have been of some benefit in this type of collision.


TIRE MARK
VI OVERRIDE MEDIAN
GRASS
CASE # 165
PSU 29
1985
CONCRETE
CONCRETE
ENTRANCE RAMP
CONCRETE MEDIAN
0
20'



YEAR: 1985
PSU: 59
CASENO: 110
NATWGT: 104.8

ACCIDENT DESCRIPTION:

Vehicle 1: '74 Freightliner CBE w/trailer, GVW=49940 lbs, 1 occupant

Vehicle 2: '74 Ford Thunderbird 2 door sedan, CW=5047 lbs, 2 occupants

On a two roadway (speed limit 45), vehicle 1 heading north was rounding a curve to the right. Vehicle 2 heading south, veered onto the north bound lane and collided in a full frontal mode with vehicle 1. Vehicle 1's front axle and vehicle 2's front bumper became detached at impact. Vehicle 1 overrode vehicle 2.

OCCUPANTS:

Vehicle 1: Driver: no information available

Vehicle 2: Driver: male, 35 yrs, 168 lbs, unrestrained
Passenger: no information available

DAMAGE:

Vehicle 1:
Location: Front
Direction of Force: 12 o'clock
Deformation: The front axle became dislodged, front fenders and hood fell off.
Intrusion: None
Ejections: None
Contact locations: Steering wheel

Vehicle 2:

Location: Front
Direction of Force: 12 o'clock
Deformation: Most of the vehicle front end was overridden. The average frontal crush was 12". The compartment integrity was not lost.
Intrusion: None
Ejections: None
Contact locations: Steering wheel and left side instrument panel and below.

ΔV:

Vehicle 1: Not calculated

Vehicle 2: 17.37 mph

Approach velocity = 19.2 mph

INJURIES:

Vehicle 1: Driver sustained minor injury.

Vehicle 2: Driver sustained a deep head laceration (AIS 2) due to contract with the steering wheel, and wrist abrasions (AIS 1) due to contact with the instrument panel.

INJURY MITIGATION AND COMMENTS:

Although this was a non-serious accident, a modified truck bumper would have prevented the override and would have absorbed some of the energy along with the passenger car's front end.

CASE # 110
PSV 59
1985

YEAR: 1985
PSU: 38
CASENO: 330
NATWGT: 76.3

ACCIDENT DESCRIPTION:

Vehicle 1: '71 Buick LaSabre, 4-door sedan hardtop, 4252 lb_f, 1 occupant.

Vehicle 3: '85 medium/heavy Mercedes-Benz single unit truck, COE, 30,000 lb_f, 1 occupant.

Impact Angle: 10 deg.

Geometric Factor: 0.5

Override Factor: 0.2

Vehicle 1, heading west on a four lane road (speed limit 35 mph), crosses center double yellow line and impacts head-on with vehicle 2 traveling eastbound. Vehicle 2 is pushed out of way. Vehicle 3, traveling behind vehicle 2, then impacts vehicle 1 and both vehicles come to rest. Travel speeds are unknown.

OCCUPANTS:

Vehicle 1: Driver, male, no other information available.

Vehicle 3: Driver, male, 30 yrs, 130 lb_f, manual lap belt not used.

DAMAGE:

Vehicle 1:
Location: Front end
Direction of force: unknown
Deformation: Direct damage across entire front bumper. Entire front end pushed evenly rearward. Engine hood buckled. Surface scratches on entire left side. Left front tire pushed outward. Left front door jammed shut. no integrity loss.
Intrusion: Intrusion of instrument panel and steering wheel.
Ejection: None
% engaged: 100%

Vehicle 3:
Location: Front end
Direction of force: 11 o'clock direction
Deformation: Minor direct damage to entire front end. No other information available. (This vehicle was inspected after being repaired. Damage estimated from photos)
Intrusion: Unknown
Ejection: None.
% Engaged: 100%

ΔV:

Vehicle 1: 30.6 mph (using momentum and truck speed of 35 mph and car speed of 0 mph)

Vehicle 3: 4.3 mph (,,)

INJURIES:

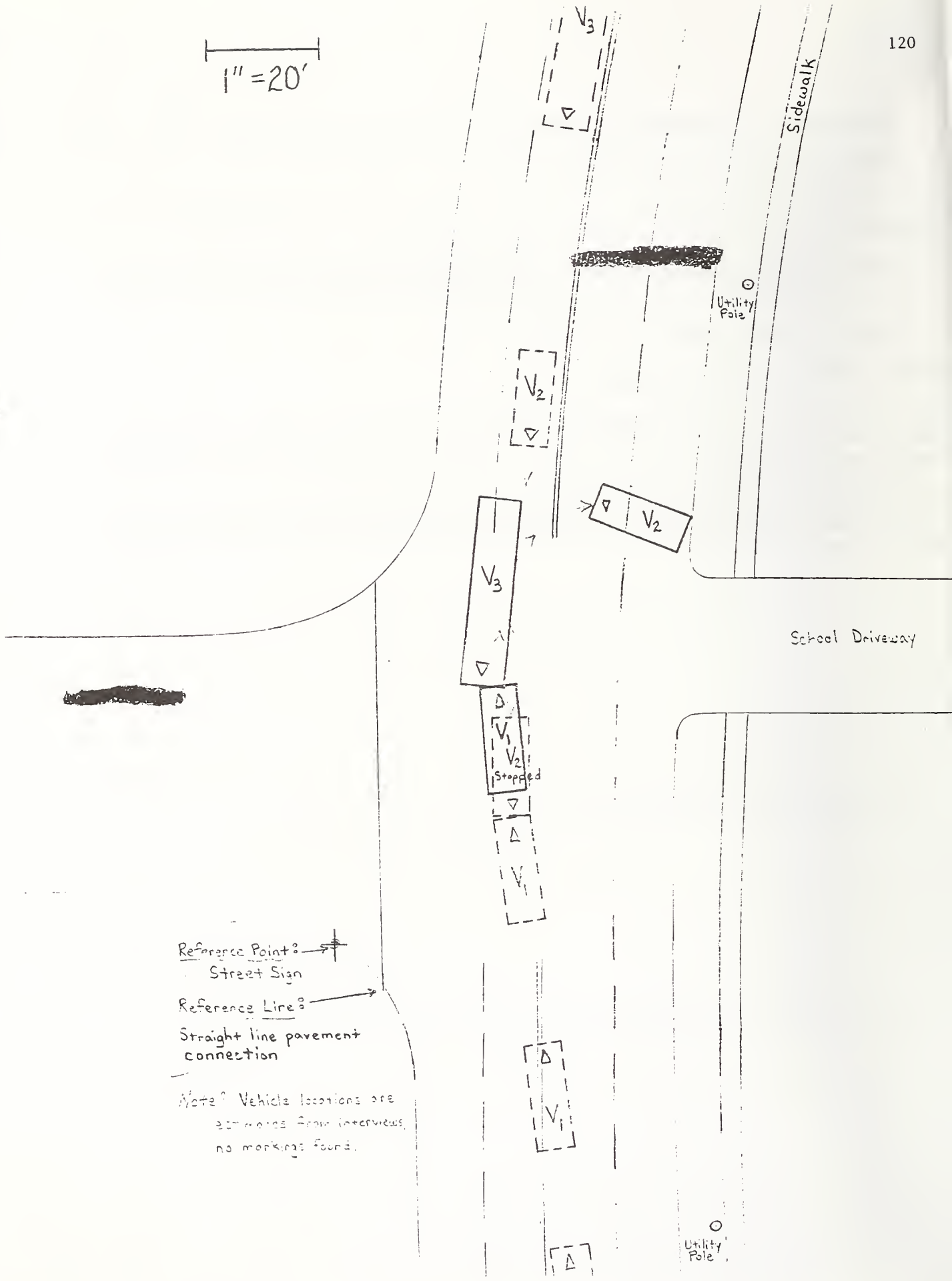
Vehicle 1: Driver: no information available. Injuries assumed to be minor, as the driver fled the scene of the accident

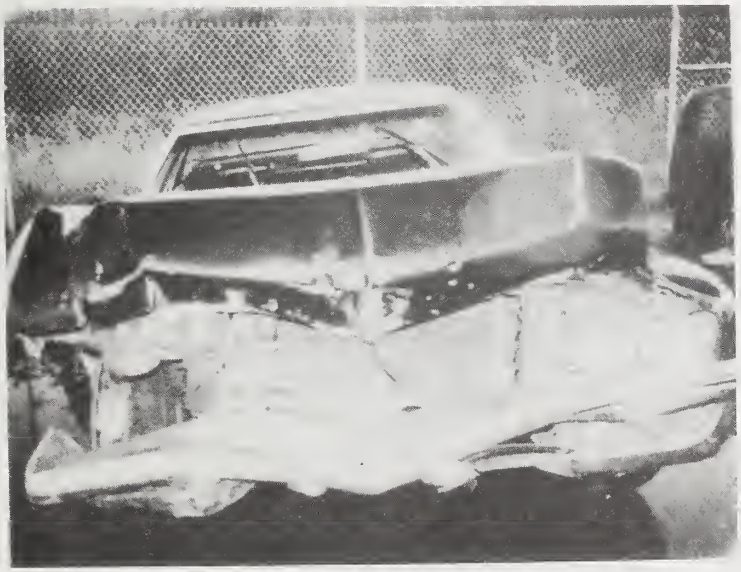
Vehicle 3: Driver: no injuries

INJURY MITIGATION AND COMMENTS:

Due to the sequence of events in this accident case and the lack of information, it is impossible to determine the damage extent to the passenger car caused by the truck. Therefore, it is impossible to address truck front-end modifications and their effects.

The reduced amount of damage to the truck and the override of the car bumper indicates that lowering and softening the truck bumper would be of some value. The accident diagram indicates that a deflecting design might also be somewhat effective.


1" = 20'
V3
Sidewalk
Utility Pole
V2
V2
V3
School Driveway
V1
V2
Stopped
V1
Reference Point: Street Sign
Reference Line: Straight line pavement connection
Note: Vehicle locations are approximate from interviews, no markings found.
V1
Utility Pole



YEAR: 1986
PSU: 58
CASENO: 176
NATWGT: 53.6

ACCIDENT DESCRIPTION:

Vehicle 1: '79 Ford 9000 CBE dump truck, GVW=67000 lbs, 1 occupant

Vehicle 2: '82 AMC Concord 4 door sedan, CW=2822 lbs, 1 occupant

Vehicle 1 was traveling west on a two lane roadway (speed limit 55 mph). Vehicle 2 for an unknown reason started to crossover the centerline and entered the same lane as Vehicle 1. Vehicle 1 tried to avoid hitting Vehicle 2, but couldn't. Vehicle 2 collided with vehicle 1 in a half-offset mode and was overridden by vehicle 1.

OCCUPANTS:

Vehicle 1: Driver: no information available

Vehicle 2: Driver: male, 34 yrs, 180 lbs, restrained (lap and shoulder belt)

DAMAGE:

Vehicle 1:
Location: Front
Direction of Force: 12 o'clock
Deformation: The truck sustained left frontal damage. Bumper was disengaged, left front fender had been ripped off, and there was also some damage to the grille.
Intrusion: None
Ejections: None
Contact locations: No visible areas of contact.

Vehicle 2:
Location: Front
Direction of Force: 12 o'clock
Deformation: Entire left half side of vehicle was destroyed. Roof was torn off.
Intrusion: Unable to be obtained due to extensive fire damage which occurred at the tow yard hours after impact.
Ejections: Ejection occurred through the driver's side door.
Contact locations: Unable to determine due to fire damage.

ΔV:

Vehicle 1: Not calculated

Vehicle 2: 32.43 mph

Approach velocity = 33.43 mph

INJURIES:

Vehicle 1: No injures listed for the driver

Vehicle 2: The driver of the car was killed.

INJURY MITIGATION AND COMMENTS:

The damage to vehicle 2 can be attributed to the geometric mismatch between the two vehicles. A modified truck bumper which is lower and softer could have been a benefit in the case. Since the collision was an offset type, a bumper design that will deflect the car would also be appropriate.

CASE # 176
PSU 52
1986

YEAR: 1986
PSU: 61
CASENO: 46
NATWGT: 117.1

ACCIDENT DESCRIPTION:

Vehicle 1: '76 Chevrolet C-20 pickup, 4,200 lb_f, four occupants

Vehicle 2: '75 Peterbilt CBE, 42,000 lb_f, one occupant

Impact Angle: +60 deg

Geometric Factor: 0.1

Override Factor: 0.1

Vehicle 1 was eastbound (speed limit 55 mph.). Vehicle 2 was entering the intersection heading north, turning west. According to both drivers, there was so much gravel and sand on the roadway in the area, it was sometimes hard to see through the dust. V1 was unable to stop before hitting V2.

OCCUPANTS:

Vehicle 1: Driver, female, 25 yrs, 134 lb_f, lap belt not used
Passenger #1, male, 5 yrs, 45 lb_f, front seat additional, unrestrained
Passenger #2, female, 8 yrs, 53 lb_f, front seat middle, lap belt unused
Passenger #3, male, 11 yrs, 90 lb_f, front seat right, lap belt unused

Vehicle 2: Driver, male, 32 yrs, 165 lb_f, lap belt unused

DAMAGE:

Vehicle 1:
Location: Front
Direction of force: 12 o'clock
Deformation: The entire front (bumper to the hood) is crushed, with crush of 20 inches on the passenger side. There seems to be no override of the pickup bumper. Integrity was lost through the windshield.
Intrusion: None
Ejections: None
Contact locations: There was occupant contact with dash, windshield on both driver and passenger side. There was also contact with the steering wheel.
% Engaged: 40 % of front

Vehicle 2:
Location: Front
Direction of force: 11 o'clock
Deformation: The left part of the bumper (beyond the frame attachment) is bent back. The left fender and wheelwell is also bent. There left wheel suspension is damaged.
Intrusion: None
Ejections: None
Contact locations: Right front door
% Engaged: 30 % front

ΔV:

Vehicle 1: 22.3 mph.

Vehicle 2: 2.2 mph.

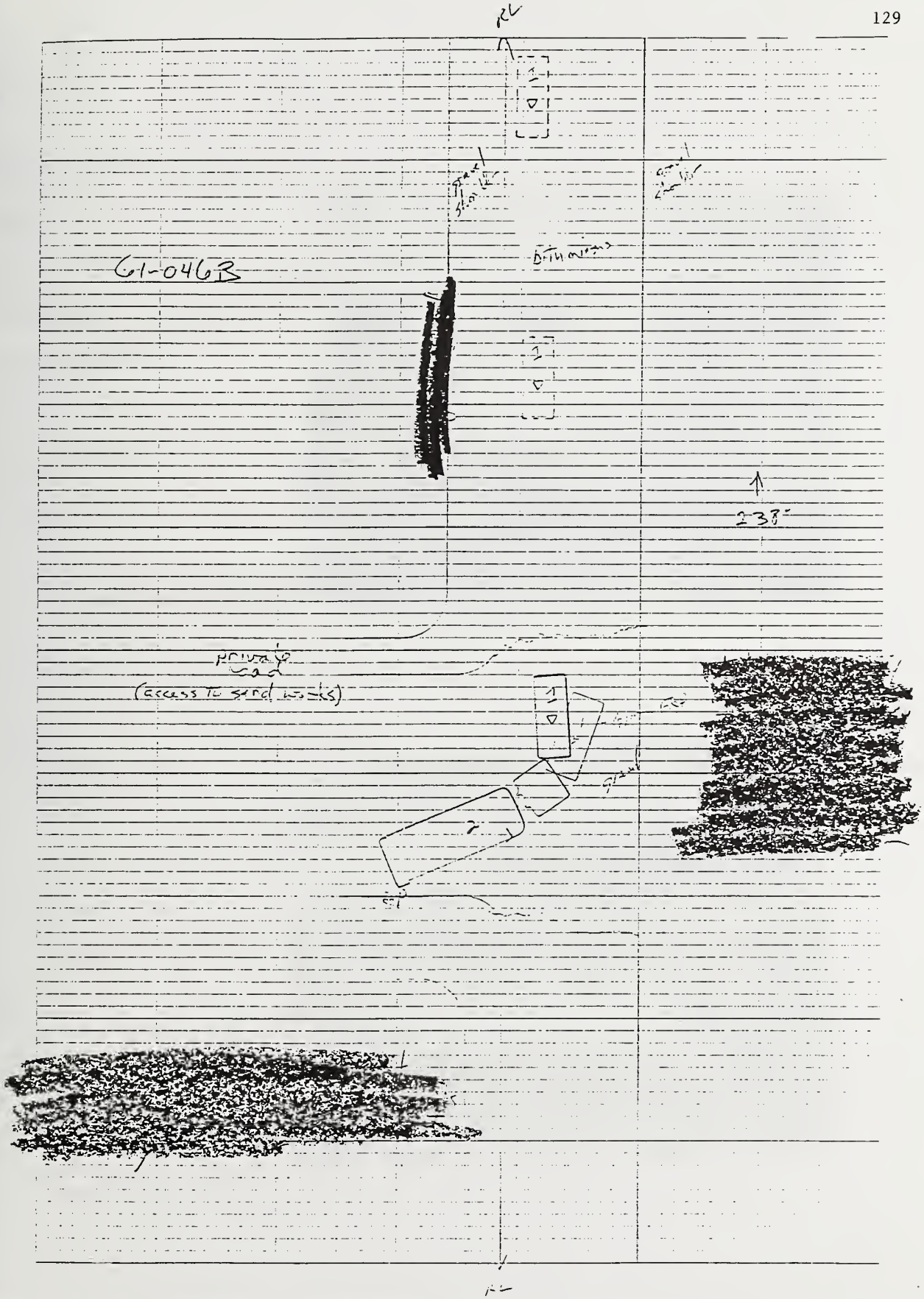
INJURIES:

Vehicle 1: Driver, hospitalized, concussion AIS 2, lacerated knees, forehead, AIS 1.
Passenger #1, hospitalized, contusion of liver AIS 3 and stomach, AIS 1
Passenger #2, hospitalized, concussion and forehead abrasions AIS 1
Passenger #3, hospitalized, lacerated forehead, AIS 1.

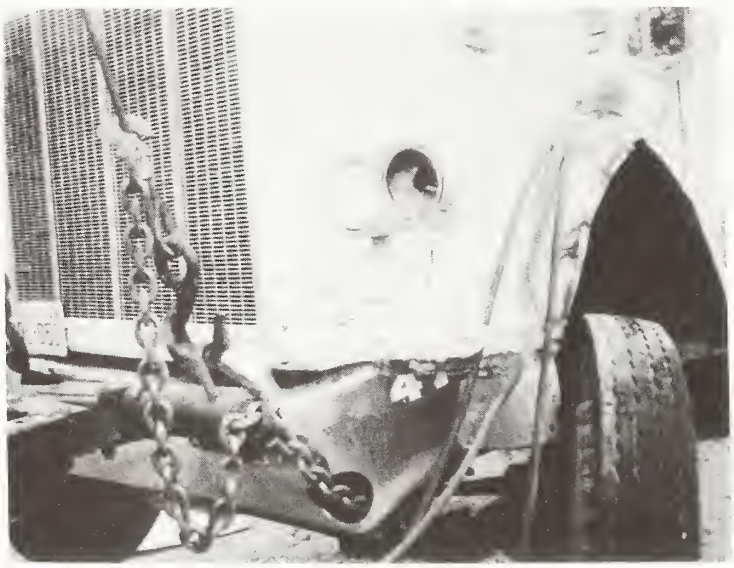
Vehicle 2: Driver, bruised right knee and left elbow AIS 1.

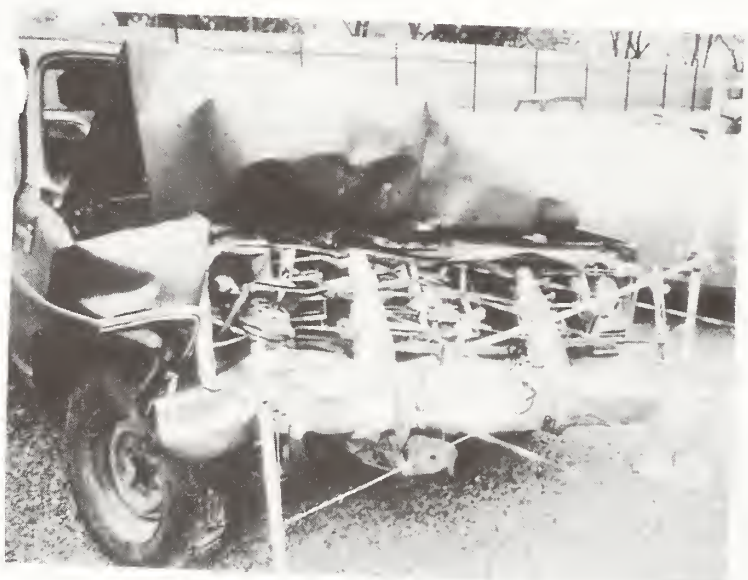
INJURY MITIGATION AND COMMENTS:

Photographs indicate no override of the pickup. However, collision geometry indicates that the pickup could have been deflected away from the truck. Also, softening the truck should reduce the severity as the stiff truck frame seems to have contacted the pickup and caused most of the damage.



46 0700





YEAR: 1986
PSU: 33
CASENO: 38
NATWGT: 73.7

ACCIDENT DESCRIPTION:

Vehicle 1: '77 Toyota Corolla 2 door, 2015 lb_f, 2 occupants

Vehicle 2: '66 International Loadstar tanker, 11500 lb_f, 1 occupant

Impact Angle: +30 deg

Geometric Factor: 0.3

Override Factor: 0.1

Vehicle 1 and 2 were travelling in opposite directions on a two lane roadway (speed limit 40 mph). V1 crossed the centerline in a no-passing zone and struck V2 headon.

OCCUPANTS:

Vehicle 1: Driver, male, 18 yrs, 145 lb_f, lap+shoulder belt not used
passenger, front right, female, 23 yrs, 100 lb_f, lap+shoulder belt not used

Vehicle 2: Driver, male, 56 yrs, 170 lb_f, restraints unavailable.

DAMAGE:

Vehicle 1:
Location: Front
Direction of force: 12 o'clock
Deformation: Considerable damage (55 inches) to the front. No override, the bumper is displaced upwards. The A, B pillars were cut with the 'jaws of life' and the roof peeled back to extricate the occupants.
Intrusion: Front (steering column) intruded by more than 12 inches.
Ejections: None
Contact locations: Steering wheel and column, right side, front and below of instrument panel
% Engaged: 90 % of front

Vehicle 2:
Location: Front
Direction of force: 12 o'clock
Deformation: Front left (beyond frame attachment) bumper bent back. left front wheel fender bent, front center (between frame attachments) bumper bent in.
Intrusion:None
Ejections: None
Contact locations: None
% Engaged: 60 % of front

ΔV:

Vehicle 1: 58.0 mph.

Vehicle 2: 10.2 mph.

INJURIES:

Vehicle 1: Driver, hospitalized for 22 days, left thigh fracture, lower jaw fracture, collapsed lung AIS 3, left knee and foot fracture AIS 2
Passenger, hospitalized 2 days, concussion AIS 2, lower lip laceration AIS 1

Vehicle 2: Driver, knee, back contusions AIS 1.

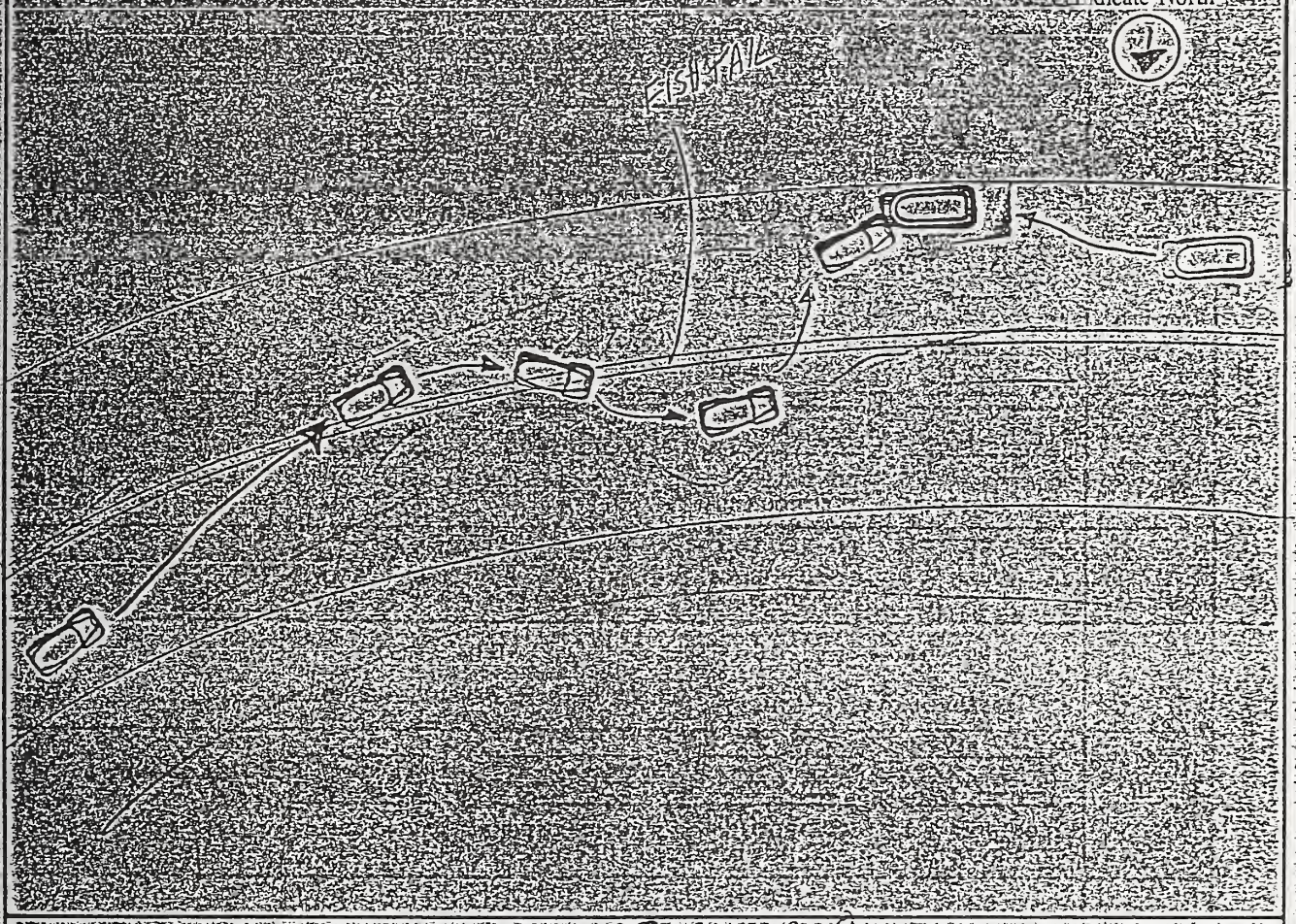
INJURY MITIGATION AND COMMENTS:

The damage pattern on the car indicates no override of the bumper. However, the damage to the truck shows that softening the truck front would have been beneficial. The frame attachment point on the bumper of the truck is not pushed back at all, and probably caused most of the damage. This case would also benefit by a deflecting truck bumper, as the accident diagram indicates that the car would have been deflected away from the truck.

ACCIDENT DIAGRAM

Draw a rough sketch of the accident sequence as described by the driver. Note impact and final rest positions carefully. If possible, relate these to some identifiable object in the area and record vehicle and pedestrian or nonmotorist headings relative to an object, as well.

Indicate North



NO CARGO

Any luggage or other cargo in vehicle when accident occurred? Estimated Weight: _____ lbs.

Describe:

Hazardous cargo in vehicle? [X] No [ ] Yes If yes, specify:

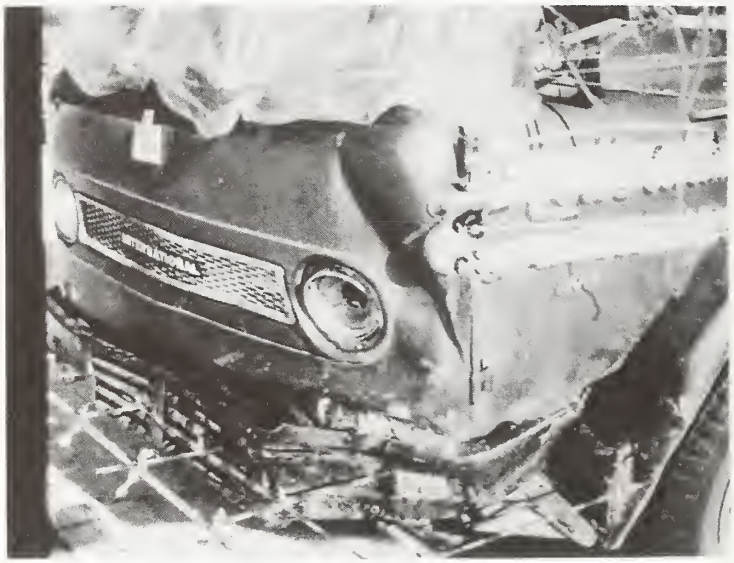
Present location of vehicle (if not yet inspected)?

Did any of the Following Restrictions of the Road Exist Prior to the Accident?

- [X] None
- [ ] Narrow bridge (as defined)
- [ ] Previous accident
- [ ] Maintenance, repair, or construction activity on roadway
- [ ] Roadway immersion (standing water)
- [ ] Unknown

Road Surface Condition

- [X] Dry
- [ ] Snow or slush
- [ ] Wet
- [ ] Ice
- [ ] Sand, dirt or oil
- [ ] Unknown



YEAR: 1986
PSU: 13
CASENO: 52
NATWGT: 92.1

ACCIDENT DESCRIPTION:

Vehicle 1: '84 GMC Astro 9000 COE, 27,000 lb_f, one occupant

Vehicle 2: '80 Ford Pinto, 2.500 lb_f, one occupant

Impact Angle: -20 deg

Geometric Factor: 0.8

Override Factor: 0.7

Vehicle 1 was heading north out of a rural town, still in a business area (speed limit 35 mph) on a dry asphalt surfaced state highway at 11 pm on a clear dark night when southbound vehicle 2 crossed the centerline on to a headon collision with V1. Both vehicles came to final resting positions near the point of impact. V1 had slowed down to 10 mph at impact and left skid marks from rear wheels of all units. No skid marks were found from V2.

OCCUPANTS:

Vehicle 1: Male, 33 yrs, 165 lb_f, lap belt used

Vehicle 2: Male, 24 yrs, 160 lb_f, lap+shoulder belt unused

DAMAGE:

Vehicle 1:

Location: Front
Direction of force: 12 o'clock
Deformation: Front bumper curved in and bowed upwards. Grill slightly damaged. Direct contact width of 60 inches, crush less than 7 inches.
Intrusion: None
Ejections: None
Contact locations: Unknown
% Engaged: 70 % front center

Vehicle 2:

Location: Front
Direction of force: 11 o'clock
Deformation: Extensive override of the front bumper, left fender crushed ~17 inches, front bumper crushed max 3 in., direct damage width of 55 in., buckling of left door, left glass broken, instrument panel 1 inch.
Intrusion: Front (steering, dash) 1 inch.
Ejections: None
Contact locations: Steering column, left a pillar and side window, driver side visor and front header, windshield, left door, armrest
% Engaged: 80 % of front

ΔV:

Vehicle 1: 1.9 mph.

Vehicle 2: 21.0 mph.

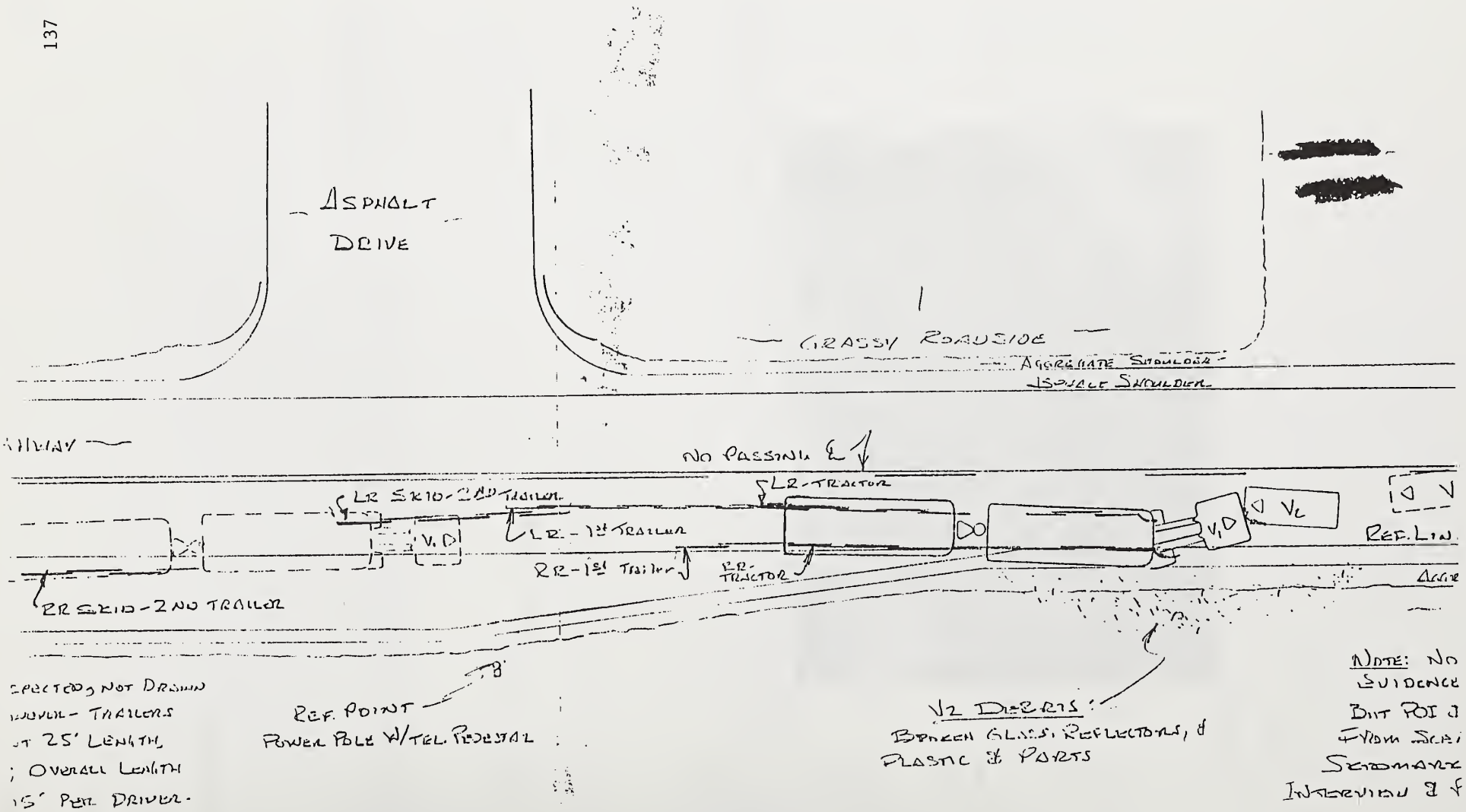
INJURIES:

Vehicle 1: None

Vehicle 2: Hospitalized, head injuries, minor bleeding, unknown AIS (assume it is 3)

INJURY MITIGATION AND COMMENTS:

The absence of truck photographs make it difficult to estimate the geometric mis-match between the car and truck fronts, or the location of impact on the truck. However, there is override of the car bumper. Lowering of the truck front would therefore be of some benefit. Also, the extent of direct damage on the car and the accident diagram indicates that narrowing the truck front would not be of any help in deflecting the car away from the truck. It could be harmful by reducing the area available for energy absorption.


ASPHALT
DRIVE
GRASSY ROADSIDE
AGGREGATE SHOULDER
PAVED SHOULDER
AIRWAY
NO PASSING
LR SKID-2ND TRAILER
LR-TRACTOR
LR-1ST TRAILER
RR-1ST TRAILER
RR-TRACTOR
RR SKID-2 NO TRAILER
V1 D
V1 D
V2
REF. LIN
ASPHA
B
B'
REF. POINT
POWER POLE W/TEL. PEDESTAL
V2 DEBRIS:
BROKEN GLASS, REFLECTORS, &
PLASTIC & PARTS
SPECTED, NOT DRAWN
NOVER-TRAILERS
AT 25' LENGTH,
; OVERALL LENGTH
15' PER DRIVER.
NOTE: NO
EVIDENCE
BUT POI
FROM SCE
SECONDARY
INTERVIEW &

YEAR: 1986
PSU: 59
CASENO: 189
NATWGT: 66.6

ACCIDENT DESCRIPTION:

Vehicle 1: '77 Mack R685ST, CBE Lowboy trailer and tractor GVW=>33000 lbs, 2 occupants

Vehicle 2: '77 Lincoln Mark 5, 2 door sedan, CW=4871 lbs, 1 occupant

On a two lane roadway, Vehicle 1 was passing a stationary vehicle 3 (not described) while heading south and vehicle 2 was passing vehicle 4 (not described) while heading north. Vehicle 1 impacted vehicle 2. The left front region of the truck (bumper and fender) engage the left front region of car above bumper.

OCCUPANTS:

Vehicle 1: Driver: unrestrained
Passenger: no information available

Vehicle 2: Driver: male, 22 yrs, 140 lbs, unrestrained

DAMAGE:

Vehicle 1:
Location: Front
Direction of Force: 12 o'clock
Deformation: Left frontal region of truck was damaged. The left quarter of the bumper was bent backward and part of the left front fender was torn off. In addition, the left front wheel of the truck was displaced.
Intrusion: None
Ejections: None
Contact locations: None

Vehicle 2:
Location: Front
Direction of Force: 12 o'clock
Deformation: Left side (front half) of car was damaged, hood was torn off, A-pillar and rood buckled. Compartment integrity was lost through the windshield and left door.
Intrusion: Steering column (>6"), A-pillar and knee panel (>12"), and left front door panel and armrest.
Ejections: None
Contact locations: Steering wheel (hub/spoke), left knee panel, door side surface including hardware and armrest.

ΔV:

Vehicle 1: Not calculated

Vehicle 2: 6.65 mph

Approach velocity = 7.21 mph

INJURIES:

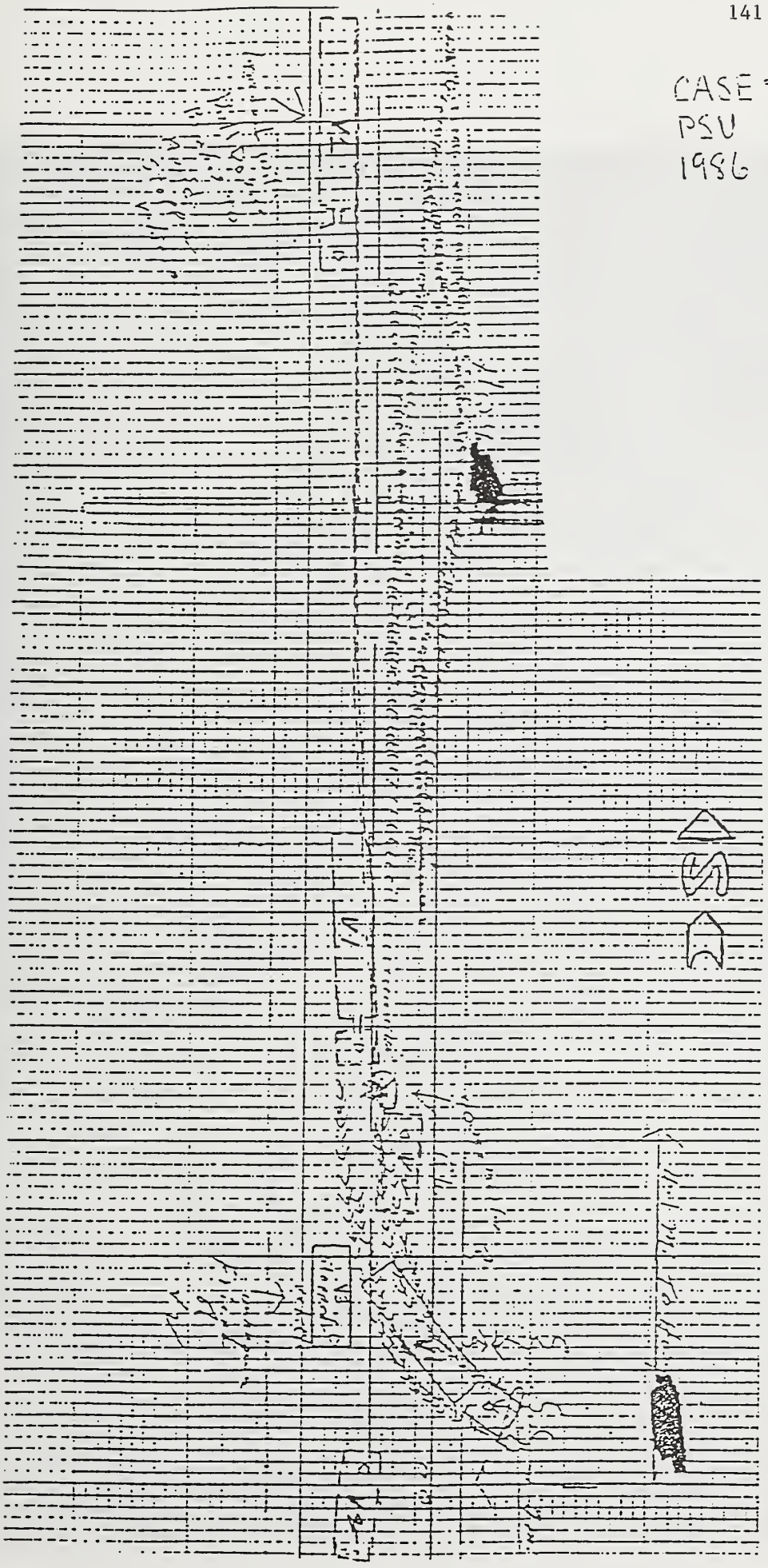
Vehicle 1: Driver not injured.

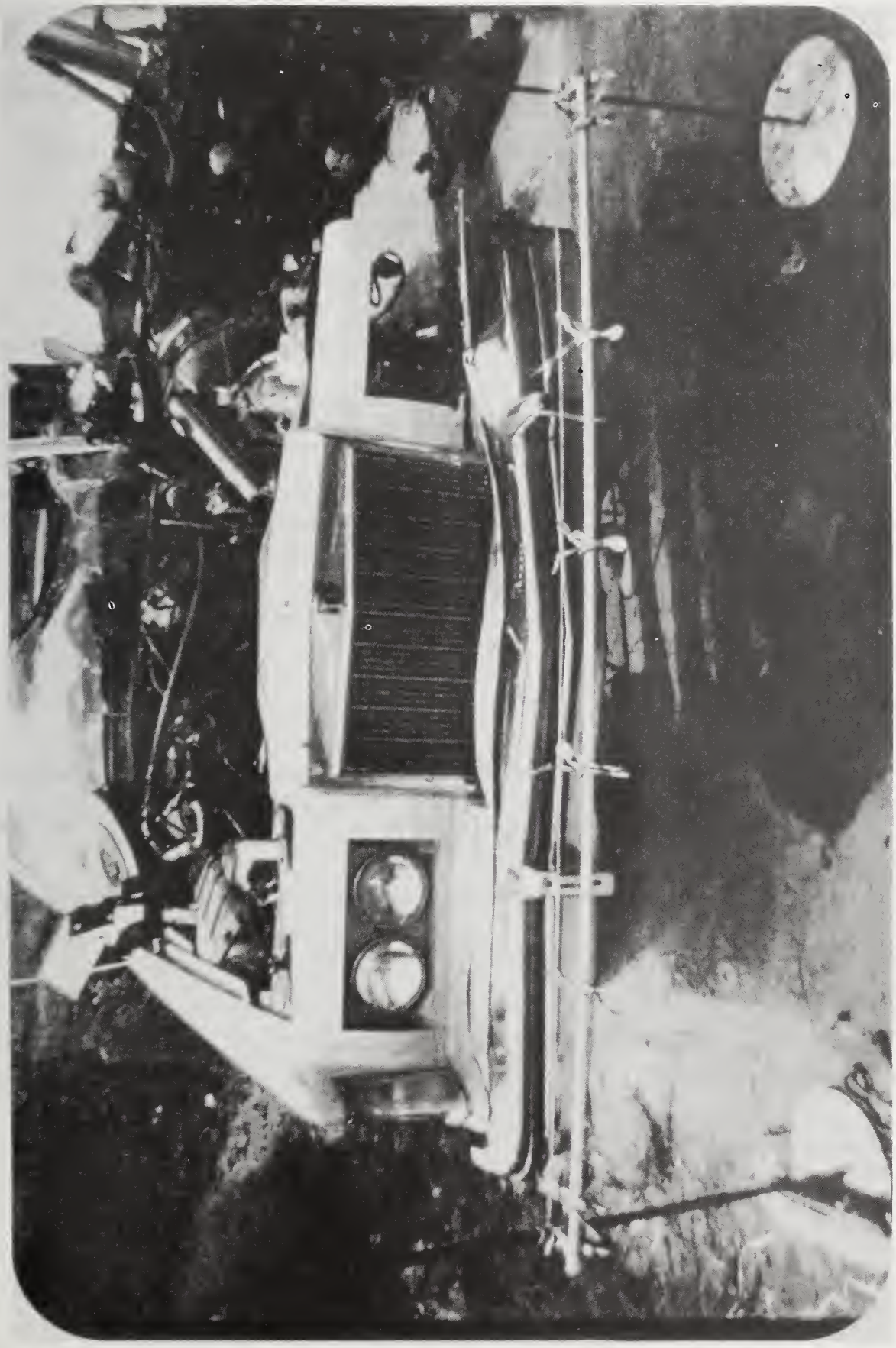
Vehicle 2: Driver sustained a sprained ankle and leg abrasions (AIS 1) due to contact with the floorboard and instrument panel respectively. In addition, driver sustained a forearm laceration (AIS) due to the contact with the side structure.

INJURY MITIGATION AND COMMENTS:

Based on the above injuries, the accident was non-serious. The damage to vehicle 2 can be attributed to the geometric mismatch between the two vehicles. A modified truck bumper would have absorbed some of the energy as well as allow the car to deflect off possibly reducing the amount of intrusion and mitigating the injuries sustained by the occupant.

CASE #189
PSU 59
1986





YEAR: 1987
PSU: 38
CASENO: 65
NATWGT: n/a

ACCIDENT DESCRIPTION:

Vehicle 1: '85 Toyota Pickup, 2700 lb_f, 2 occupants

Vehicle 2: '77 Fire truck, weight > 10,000 lb_f, 1 occupant

Impact Angle: +25 deg.

Geometric Factor: 0.3

Override Factor: 0.4

Vehicle 1, on a curved road, lost control and spun into path of vehicle 2. Vehicle 2 pulled to the right to avoid accident, but struck vehicle 1. The speed limit was 40 mph.

OCCUPANTS:

Vehicle 1: Driver, male, 22 yrs, unknown weight, lap+shoulder belt used.
Front right passenger, male, 19 yrs, unknown weight, restraints not used.

Vehicle 2: Driver, everything unknown

DAMAGE:

Vehicle 1:
Location: Front
Direction of force: 1 o'clock
Deformation: Extensive. The average crush was 35 inches. The entire front, above the frame was pushed back.
Intrusion: Extensive. The instrument panel was pushed all the way into the occupant compartment (> 12 inches). Both occupants were entrapped.
Ejections: None
Contact locations: There was contact with steering wheel and column, instrument panel and below, floor.
% Engaged: 100 of front

Vehicle 2:
Location: Front
Direction of force: Unknown (11 o'clock from accident diagram)
Deformation: Unknown
Intrusion: Nil
Ejections: None
Contact locations: None
% Engaged: Unknown

ΔV:

Vehicle 1: 34.2 mph.

Vehicle 2: 4.6 mph.

INJURIES:

Vehicle 1: Driver, killed, abdominal lacerations of spleen, colon, AIS 4, abrasions of upper chest, AIS 3, extensive contusion of lungs AIS 3, Fractured ribs, thighs AIS 3.
Passenger, killed, lacerated chest and heart, AIS 5, extensive internal injuries to lungs, spleen, kidney, AIS 4, fractured thighs AIS 3.

Vehicle 2: Driver, injuries unknown.

INJURY MITIGATION AND COMMENTS:

The injuries to both the occupants of the pickup are extensive and severe. The absence of truck damage information makes it difficult to estimate the extent of geometric and stiffness mismatch. It seems (from the photographs) from the extent of damage to the pickup, that the speeds involved were very high. However, the pickup bumper seems to have been involved (though the front frame is not). Also, the geometry of the impact (from the accident diagram and pickup damage), it seems that the pickup could have been deflected out of the path of the truck by a suitable front end design.

6.2 Side impacts

The following pages describe the NASS hardcopies for side impacts.

YEAR: 1981
PSU: 30
CASENO: 15
NATWGT: 461.23

ACCIDENT DESCRIPTION:

Vehicle 1: '73 Chevrolet single unit beverage truck, 26000 < GVW ≤ 33000 lbs, 1 occupant

Vehicle 2: '77 Plymouth Volare, 4 door sedan, 3 occupants

Vehicle 1 heading south appears to have gone through a stop sign at a 4-way intersection. Vehicle 2 heading west was struck on its right side by vehicle 1. Photographs of the damage sustained by both vehicles were not available.

OCCUPANTS:

Vehicle 1: Driver: no information available

Vehicle 2: Driver: no information available
Passenger: right front and rear seated. No other information available.

DAMAGE:

Vehicle 1:
Location: Front
Direction of Force: 12 o'clock
Deformation: The middle of the truck front bumper sustained some small dents.
Intrusion: None
Ejections: None
Contact locations: None

Vehicle 2:
Location: Right side (rear half)
Direction of Force: 3 o'clock
Deformation: Most of the damage occurred on the right rear door and the remaining portion was on the rear quarter panel. In addition, the right rear window was broken.
Intrusion: Through right rear side of compartment.
Ejections: None
Contact locations: Contact occurred with the C-pillar.

ΔV:

Vehicle 1: Not calculated

Vehicle 2: Not calculated

Approach velocity = Not calculated

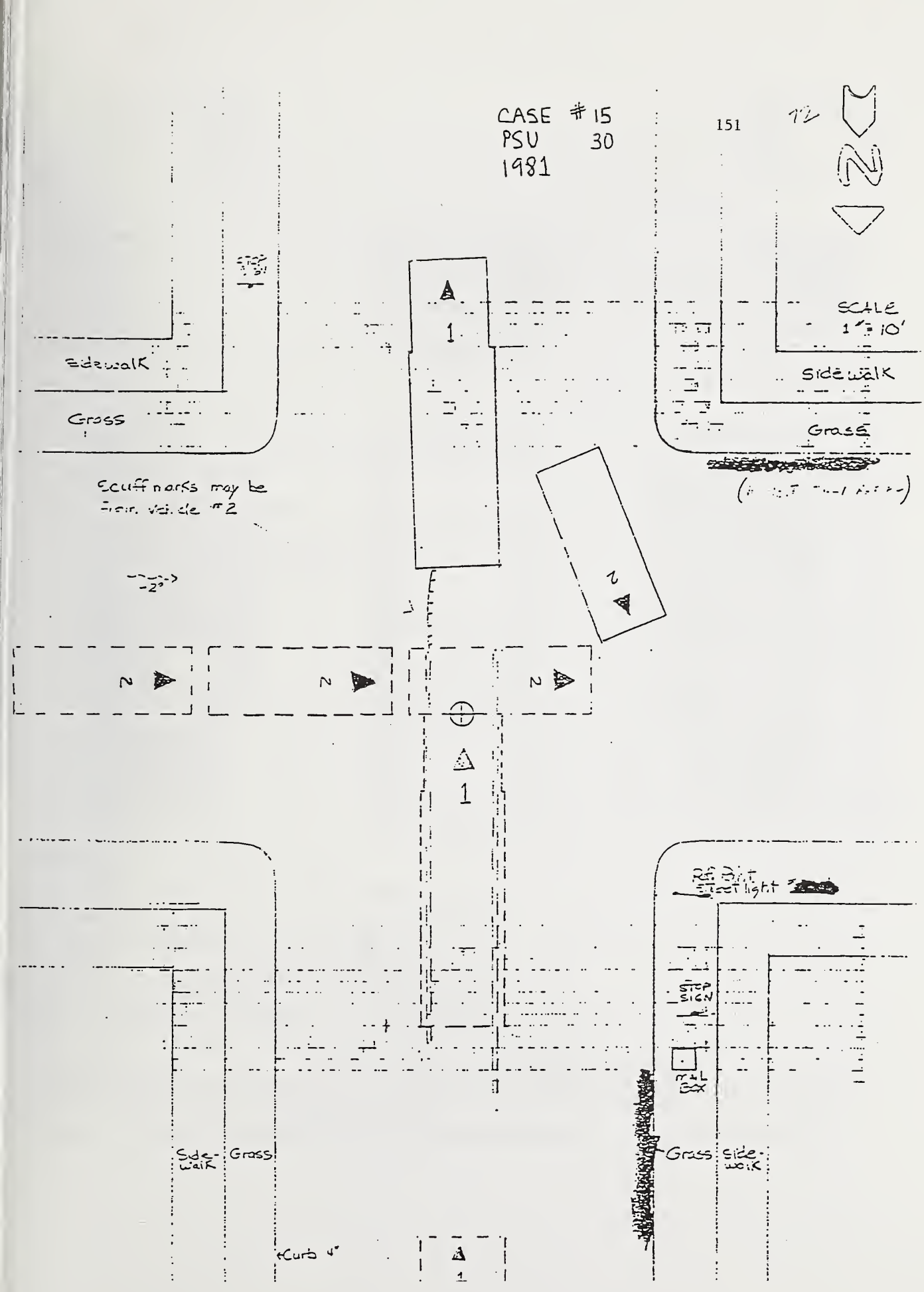
INJURIES:

Vehicle 1: The driver of vehicle 1 sustained no injuries.

Vehicle 2: The driver of vehicle 2 sustained no injuries. The right front passenger sustained right and left knee contusions and abrasions (AIS 1) due to contact with the lower instrument panel. The right rear passenger sustained contusions to the forehead (AIS 1) due to the contact with the C-pillar. In addition, the passenger sustained contusions to the occipital area and gluteal area (AIS 1)

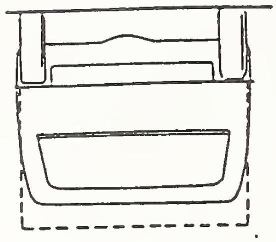
INJURY MITIGATION AND COMMENTS:

Since the passenger car was impacted primarily on its right rear door, it is unlikely that a modified truck bumper would have been a benefit in the accident case.


CASE #15
PSU 30
1981
151
SCALE
1" = 10'
Sidewalk
Grass
Sidewalk
Grass
Scuff marks may be
from vehicle #2
1
2
2
2
1
Red Dot
Street light
STOP
SIGN
Mail
Box
Side-
walk
Grass
Curb 4"
Grass
Side-
walk
1

STRAIGHT TRUCKS
- Flat Bed/Platform
- Stake Bed
- Box or Van Body
- Tank
- With Single or Double Rear Axle

} CARGO CONFIGURATION



Number of Axles:

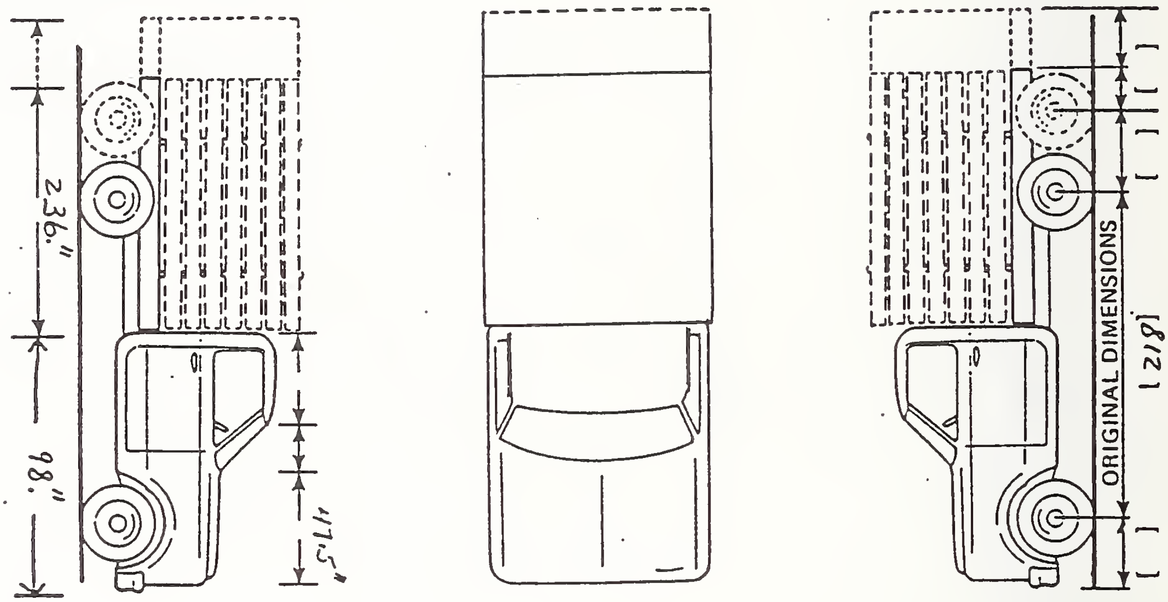
Total 2

Truck ____

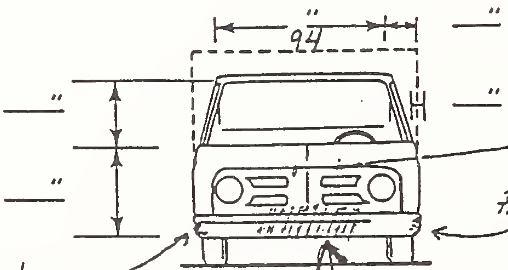
Semi ____

Full ____

VEHICLE 1



List any tires which are deflated due to damage on the back of this page.

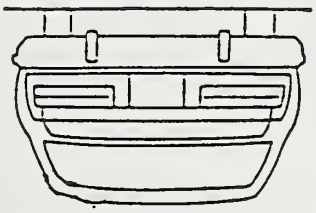


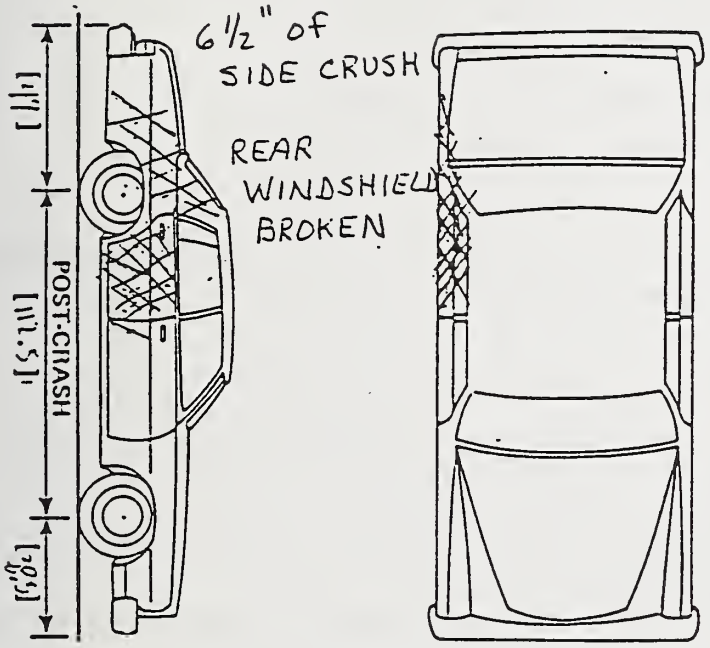
Note: Sketch new perimeter and shade damage. Annotate observations which might be useful in reconstructing the accident (e.g., grass in tire bead, direction of striations, scuff on sidewall, etc.).

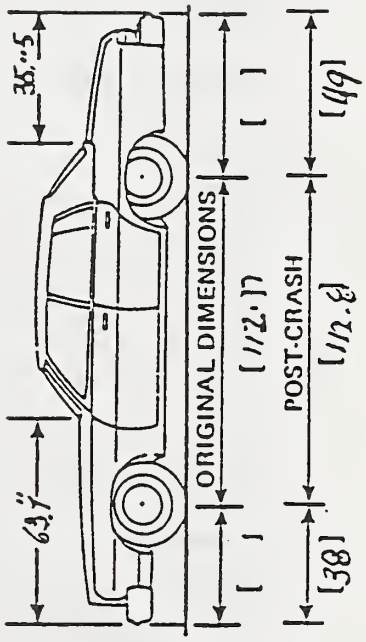
If pulling trailer sketch type of trailer and damage received on reverse side.

CASE # 15
PSU 30
1981

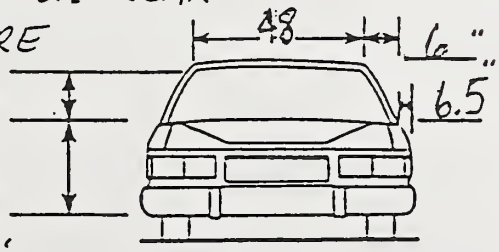
VEHICLE 2







MOST OF DAMAGE IS ON REAR DOOR. SOME DAMAGE ON REAR QUARTER PANEL. THERE WAS SOME REAR 16" INTRUSION. CANNOT IDENTIFY 32" AMOUNT FROM PHOTOS.



YEAR: 1982
PSU: 54
CASENO: 108
NATWGT: 151.4

ACCIDENT DESCRIPTION:

Vehicle 1: '72 GMC C-Series straight truck, GVW > 26000 lbs, 1 occupant

Vehicle 2: '79 Dodge W-Series pickup, 3 occupants

Vehicle 1 was heading east through a 4-way intersection and struck vehicle 2 in he right rear quarter panel area. Vehicle 2 went through a stop sign. The driver of vehicle 2 may have had his vision impaired by trees and shrubs.

OCCUPANTS:

Vehicle 1: Driver: no information available

Vehicle 2: Driver: no information available

DAMAGE:

Vehicle 1:
Location: Front
Direction of Force: 12 o'clock
Deformation: Minor damage to bumper and grille area.
Intrusion: None
Ejections: None
Contact locations: None

Vehicle 2:
Location: Right side (rear region)
Direction of Force: 3 o'clock
Deformation: Flatbed was distorted. Unable to determine the amount of side crush due to lack of data.
Intrusion: Unable to determine due to lack of data.
Ejections: There was one passenger whom was riding on the flatbed that was thrown out at the time of the accident.
Contact locations: Unknown due to lack of data.

ΔV:

Vehicle 1: Not calculated

Vehicle 2: Not calculated

Approach velocity = Not calculated

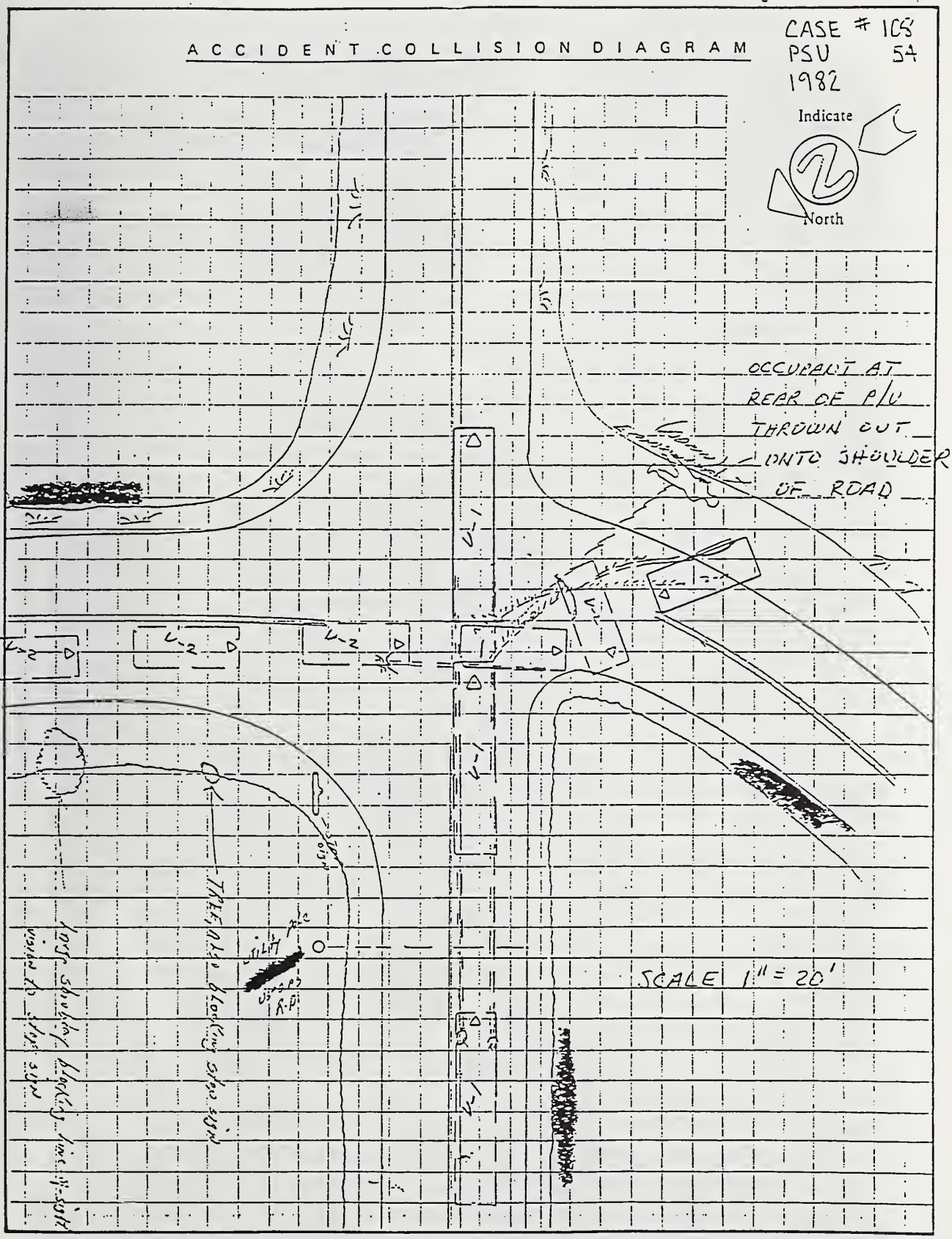
INJURIES:

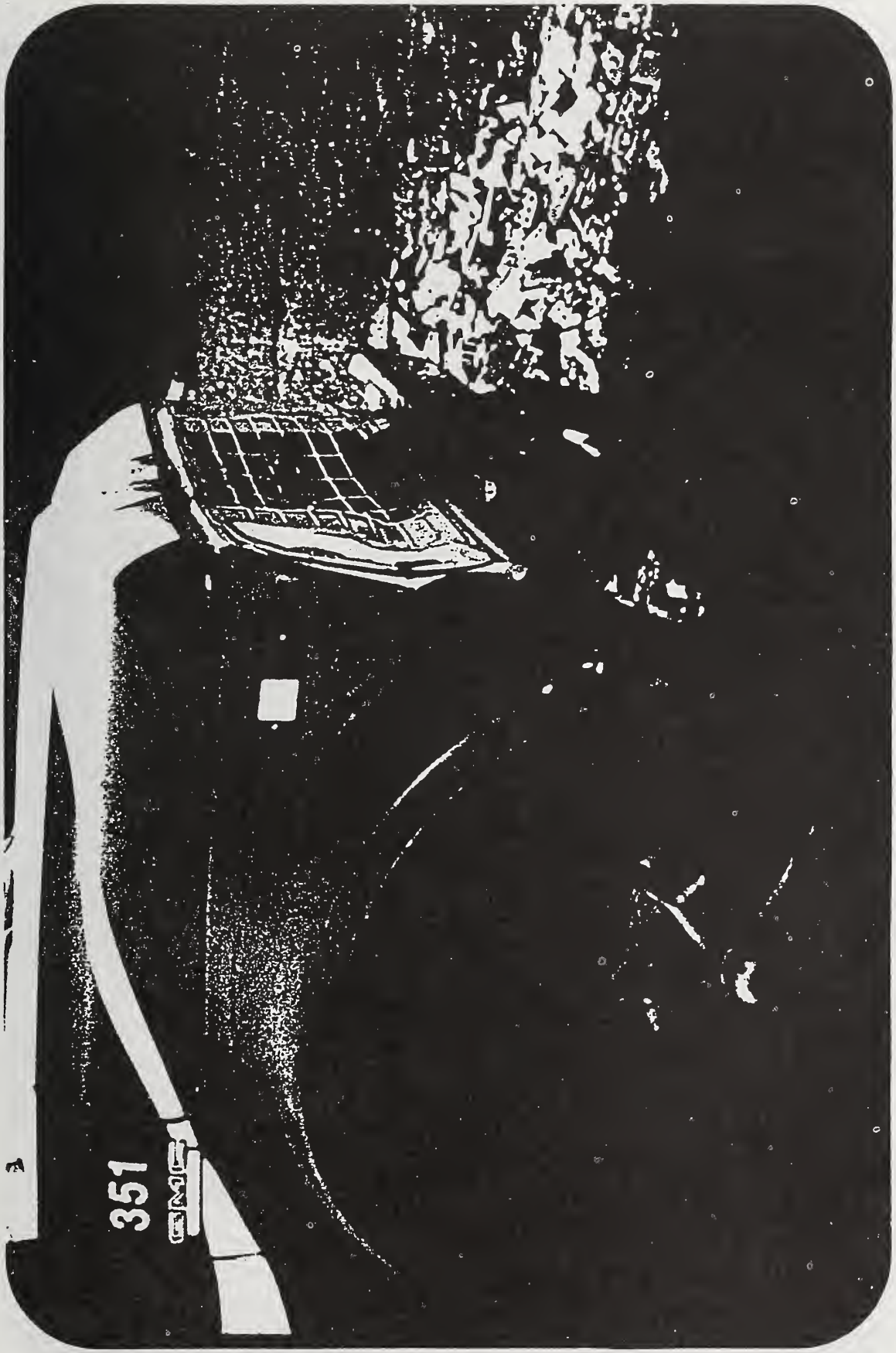
Vehicle 1: Information not available

Vehicle 2: The driver and two passengers sustained minor injuries (AIS 1). The injury location was not available due to lack of data.

INJURY MITIGATION AND COMMENTS:

It is unlikely that a modified truck bumper would have mitigated the vehicle damage or occupant injury.


ACCIDENT COLLISION DIAGRAM
CASE # 105
PSU 54
1982
Indicate
North
OCCUPANT AT REAR OF P/U THROWN OUT INTO SHOULDER OF ROAD
V-1
V-2
SCALE 1" = 20'


351

YEAR: 1982
PSU: 27
CASENO: 110
NATWGT: 80.6

ACCIDENT DESCRIPTION:

Vehicle 1: '73 Buick Opel, 5 occupants

Vehicle 2: '69 Mack CBE w/o trailer, GVW > 33000 lbs, 1 occupant

On a two lane roadway, vehicle 1 travelling north skidded onto the southbound lane and was struck by vehicle 2.

OCCUPANTS:

Vehicle 1: Driver: no information available
Passenger: no information available

Vehicle 2: Driver: no information available

DAMAGE:

Vehicle 1:
Location: Side (center region)
Direction of Force: 3 o'clock
Deformation: Difficult to determine the amount of damage due to lack of data. The center portion of the right side of vehicle 1 was damaged.
Intrusion: Unknown due to lack of data.
Ejections: Unknown due to lack of data.
Contact locations: Unknown due to lack of data.

Vehicle 2:

Location: Front
Direction of Force: 12 o'clock
Deformation: Vehicle 2 sustained minor frontal damage.
Intrusion: None
Ejections: None
Contact locations: Unknown due to lack of data.

ΔV:
Vehicle 1: Not calculated

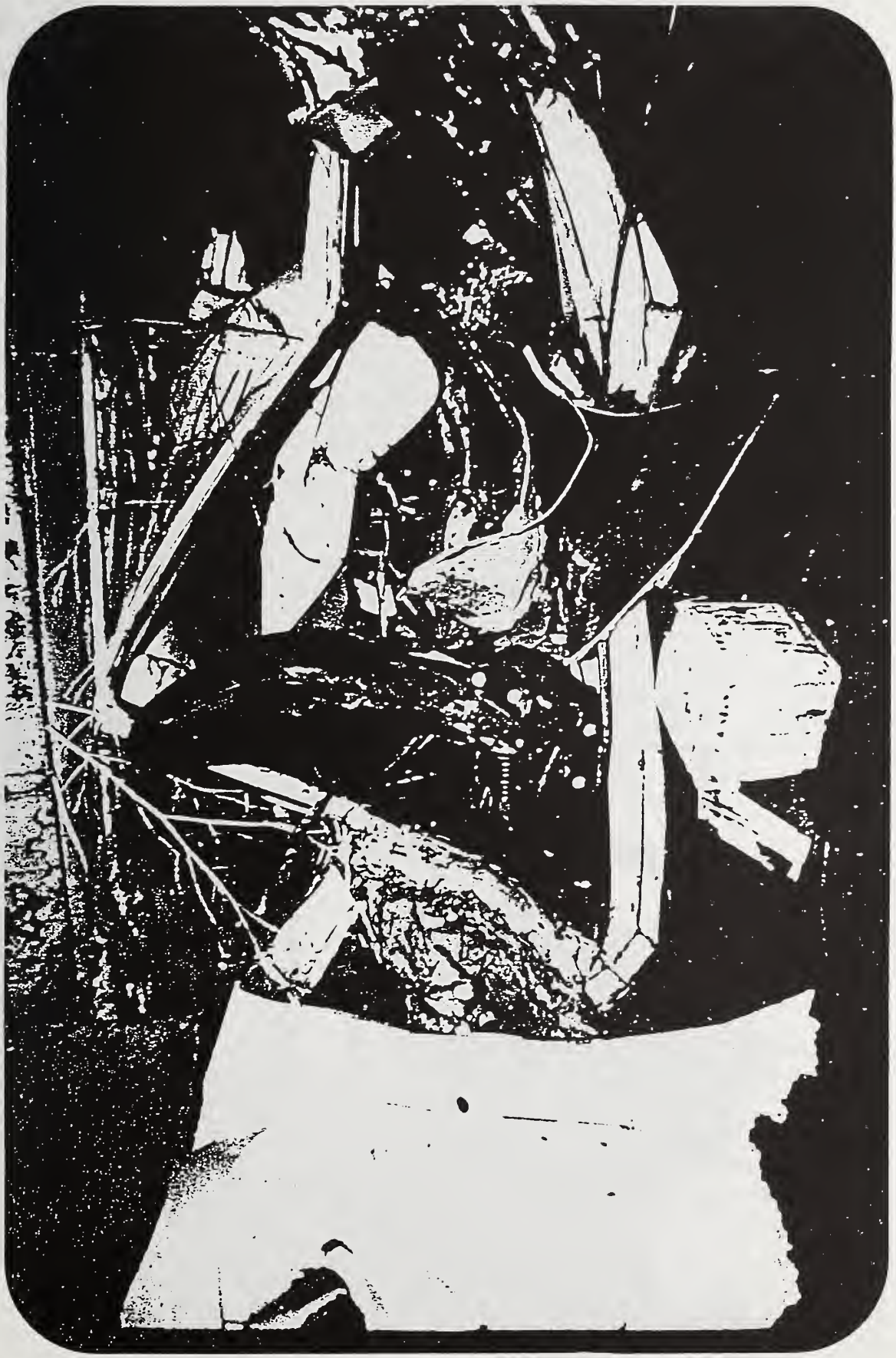
Vehicle 2: Not calculated

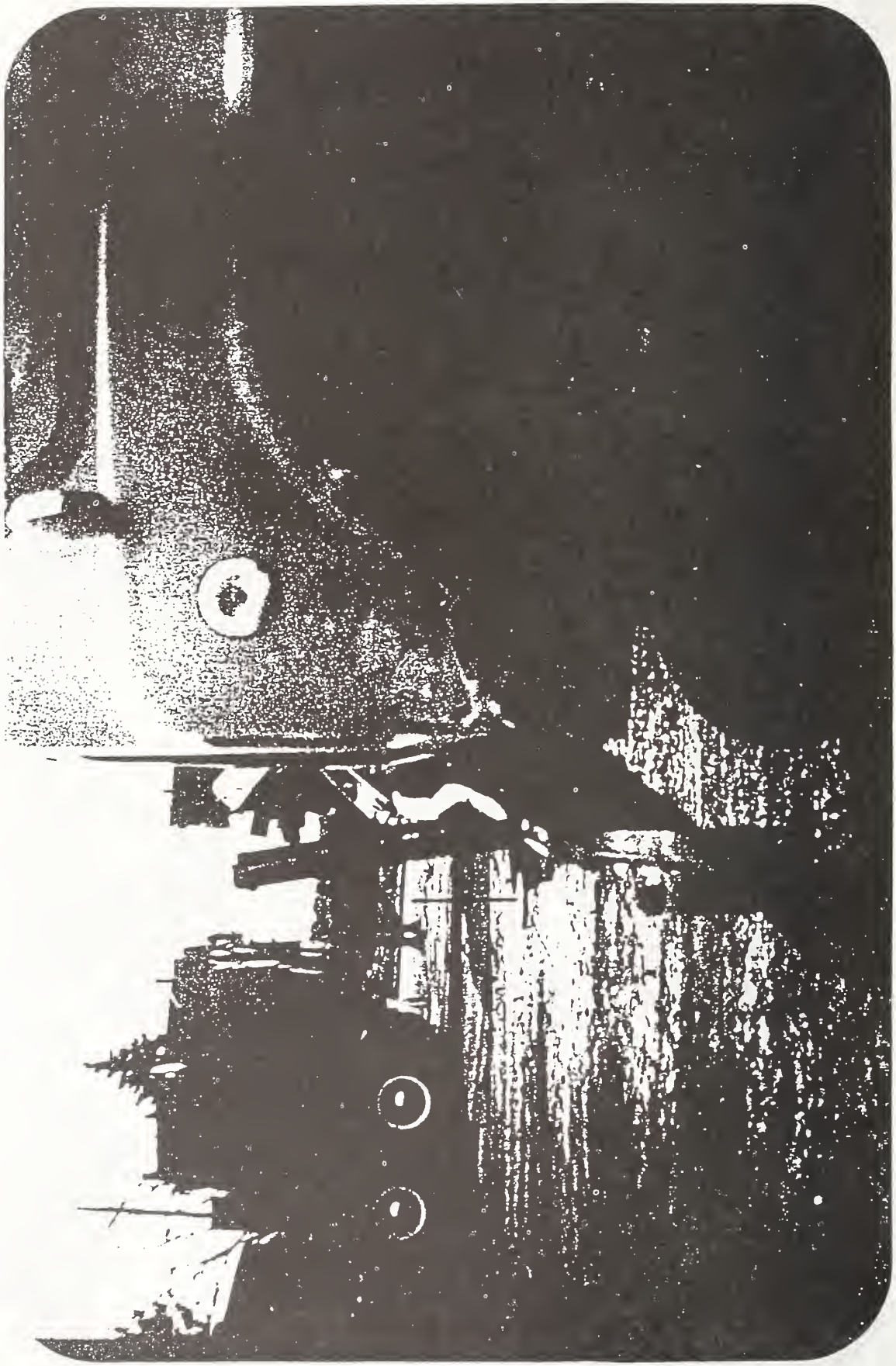
Approach velocity = Not calculated

INJURIES:
Vehicle 1:

Vehicle 2:

INJURY MITIGATION AND COMMENTS:





YEAR: 1982
PSU: 30
CASENO: 224
NATWGT: 95.2

ACCIDENT DESCRIPTION:

Vehicle 1: '73 straight unit dump truck, GVW > 33000 lbs, 1 occupant

Vehicle 2: '74 Dodge Coronet, 4 door sedan, 1 occupant

Vehicle 2 heading south drove through a stop sign at a 4-way intersection. Vehicle 1 heading east collided with vehicle 2. The left front bumper of vehicle 1 engaged the right front fender of vehicle 2.

OCCUPANTS:

Vehicle 1: Driver: no information available

Vehicle 2: Driver: no information available

DAMAGE:

Vehicle 1:
Location: Front
Direction of Force: 12 o'clock
Deformation: There was minor damage to the left front bumper.
Intrusion: None
Ejections: None
Contact locations: None

Vehicle 2:
Location: Right side (frontal region)
Direction of Force: 3 o'clock
Deformation: Upper half of right front fender was damaged.
Intrusion: None
Ejections: None
Contact locations: Unknown due to lack of data.

ΔV:

Vehicle 1: Not calculated

Vehicle 2: Not calculated

Approach velocity = Not calculated

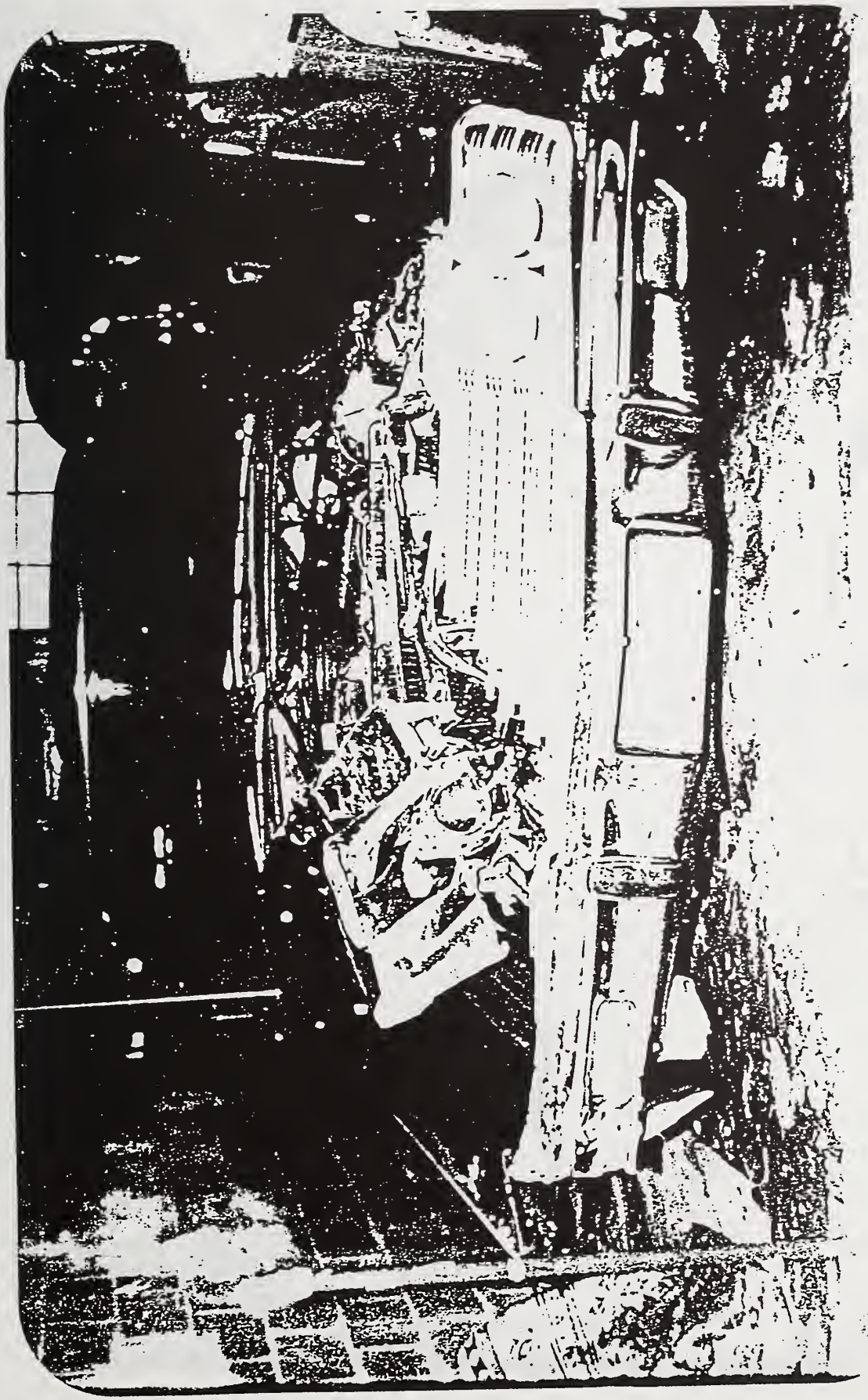
INJURIES:

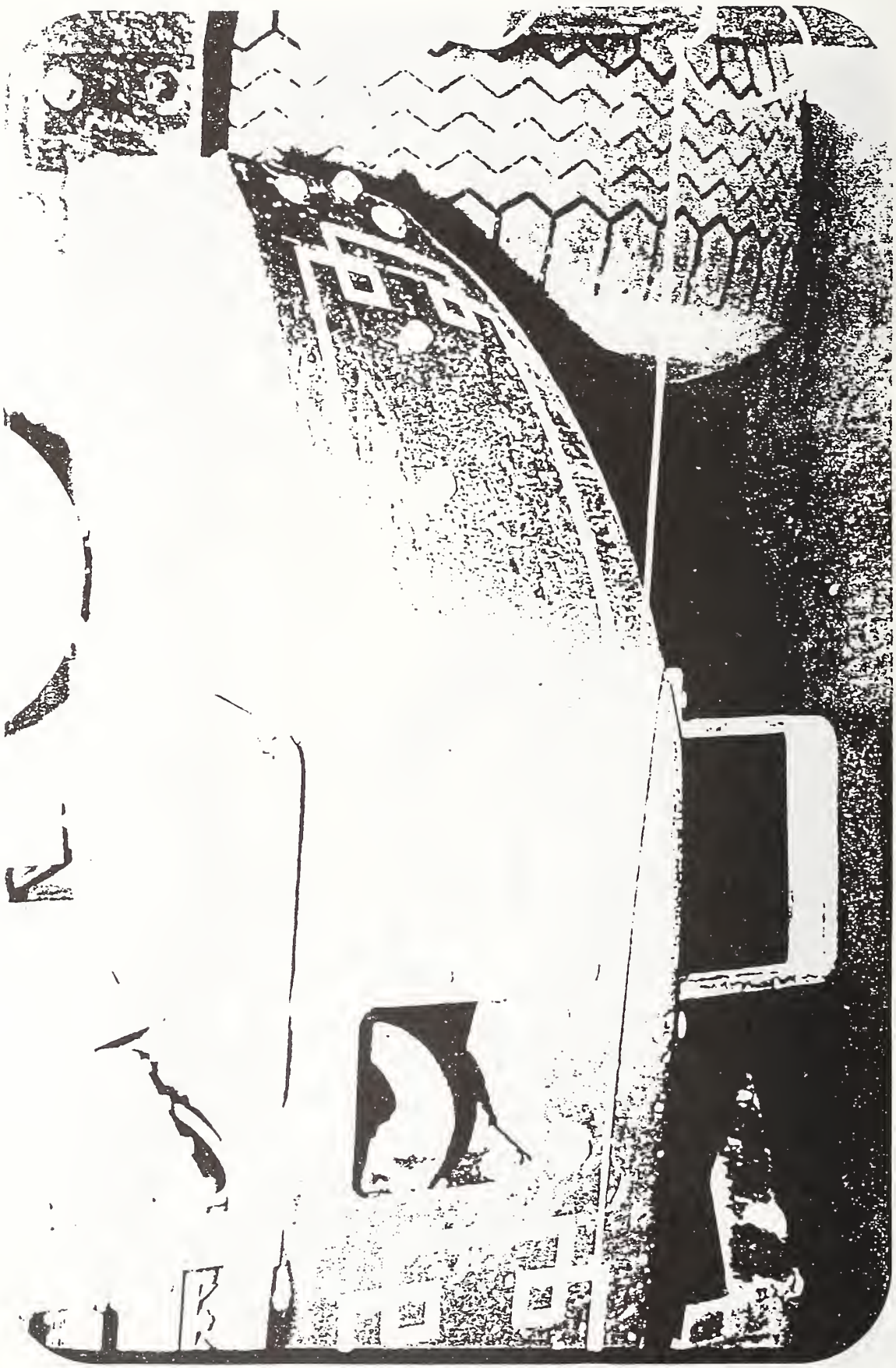
Vehicle 1:

Vehicle 2:

INJURY MITIGATION AND COMMENTS:

CASE # 224
PSU 30
1982
V-1 - 73 AUTOCAR T
V-2 - 74 DODGE CORO
GAS STATION
BANK
STOP
PAVE
V2
V-1
D
Curb
ENTRANCE





YEAR: 1982
PSU: 84
CASENO: 036
NATWGT: 159.1

ACCIDENT DESCRIPTION:

Vehicle 1: '74 White medium/heavy tractor-trailer, COE, 2 occupants.

Vehicle 2: '76 Chevrolet Suburban, 4-door, 4300 lb_f, 1 occupant.

Vehicle 2, traveling on shoulder of 2-lane road (speed limit 55 mph), attempts to make a left-hand turn into a private drive and crosses into path of oncoming vehicle 1. Front right side of vehicle 2 strikes vehicle 1 on left side at an angle and pushes vehicle 2 down the road. Driver of vehicle 2 is entrapped. Travel speeds are unknown.

OCCUPANTS:

Vehicle 1: Driver, male, 39 yrs, 285 lb_f, no manual or automatic restraint system available.
Right front passenger, male, 23 yrs, 165 lb_f, lap belt not used.

Vehicle 2: Driver, male, 67 yrs, 185 lb_f, manual lap+shoulder restraint not used.

DAMAGE:

Vehicle 1:
Location: Right half of front end
Direction of force: 12 o'clock direction
Deformation: Right side of bumper has pivoted around attachment point to expose right tire. Front grill loosened and pushed inward. Section of sheet metal above bumper has been torn away. Remaining sheet metal is scratched and dented up to windshield.
Intrusion: No intrusion
Ejection: None

Vehicle 2:
Location: Left side
Direction of force: 8 o'clock direction
Deformation: Direct damage to left side beginning at front door and extending to end of vehicle. Direct damage along entire height of vehicle. A and B-pillar pushed inward. C-pillar completely torn away. Left roof side rail pushed inward. Front and rear left doors separated from door latch strikers. Left sill engaged and pushed inward. Vehicle's frame exposed. Integrity loss through left front and rear side doors.
Intrusion: Maximum intrusion to left front side door greater than 15 cm.
Ejection: None.

ΔV:

Vehicle 1: Not calculated.

Vehicle 2: Not calculated.

INJURIES:

Vehicle 1: Driver: left shoulder contusion - ais 1, contusion to right side of face - ais 1.
Passenger: Not injured.

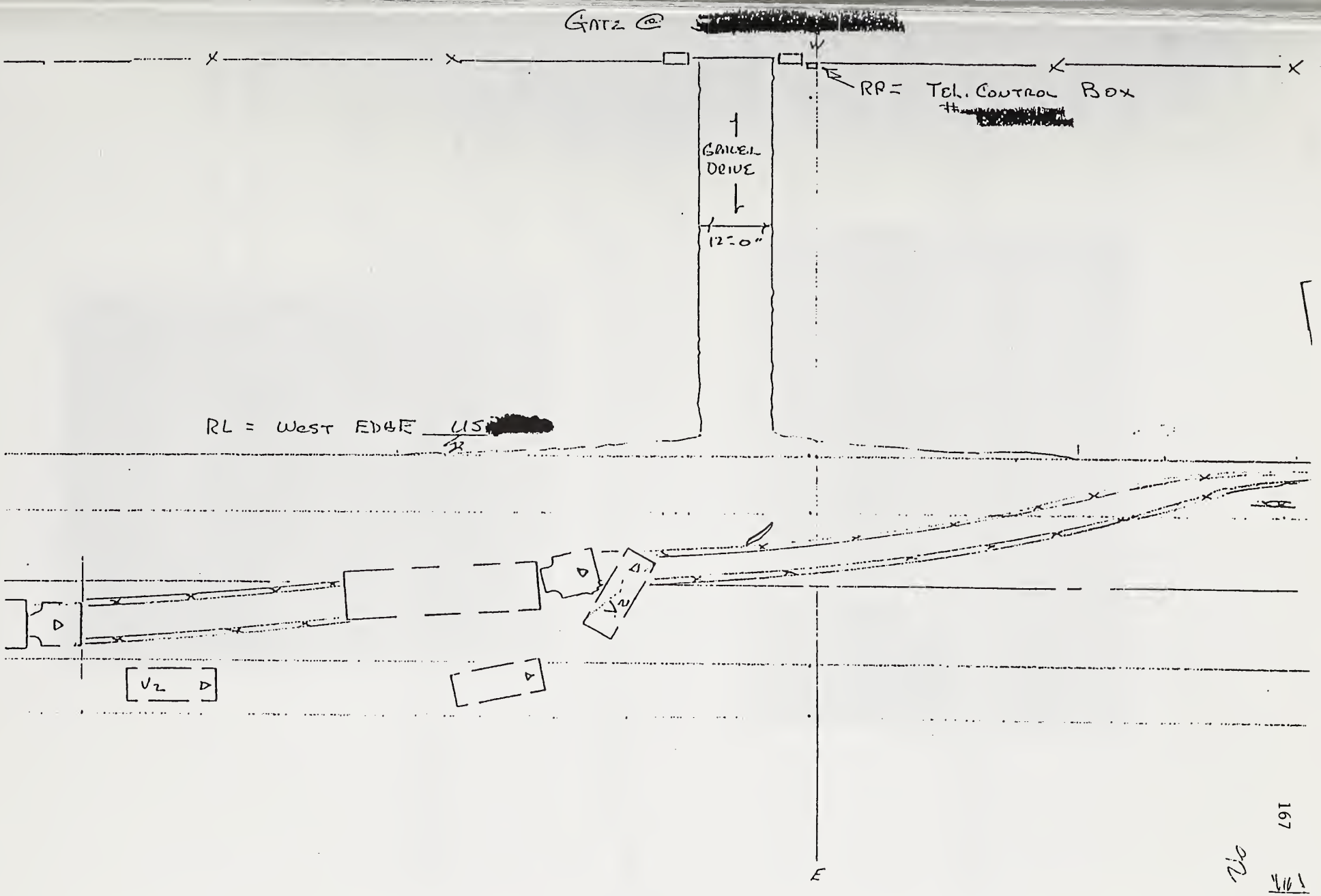
Vehicle 2: Driver: ribs fractured on left side - ais 2, left forearm fractured - ais 2, laceration to right wrist - ais 1, contusion on lower back - ais 1, contusion on right side of head - ais 1.

INJURY MITIGATION AND COMMENTS:

A better geometric match seems to be present with the two vehicles involved in this case. The Suburban's sill height matches the height of the truck's front bumper much closer than that of a passenger car. Although the truck's front-right tire was exposed and perhaps even made contact with the Suburban, it does not appear that any sill-override occurred. It seems likely that engagement with the Suburban's door sill provided more structural resistance and may have prevented further occupant compartment intrusion.

However, the damage to the Suburban is still very severe, possibly due to the angle at which the truck appears to have made contact. Evidence showing the bumper bending around the frame support suggests that the truck's frame is involved in the impact and does not absorb any energy. It is concluded that a reduction of the stiffness characteristics on the truck's front-end would decrease the impact severity in this case.

Due to the impact locations on the vehicles, it does not appear that a deflecting structure on the front-end of the truck would work properly and may, in fact, add to the severity by offering less area on the truck's front to absorb the impact load.


GATE @ [redacted]
RR = TEL. CONTROL BOX
[redacted]
GRAVEL DRIVE
12'-0"
RL = WEST EDGE US [redacted]
D
D
V2
D
V2
D
E
167
GRASS:

YEAR: 1983
PSU: 12
CASENO: 124
NATWGT: 121.7

ACCIDENT DESCRIPTION:

Vehicle 1: '76 Chevrolet C65 single unit truck, 14500 lb_f, 2 occupant.

Vehicle 2: '71 Volkswagen Beetle, 2-door sedan, hardtop, 1807 lb_f, 2 occupants.

Vehicle 2 backs out of private drive into 2-lane road (speed limit 55 mph) and crosses into path of oncoming vehicle 1. Right front-end of vehicle 1 strikes vehicle 2 in passenger door at an angle. Both vehicles continue down road locked together until coming to final resting position. Travel speeds are unknown.

OCCUPANTS:

Vehicle 1: Driver, male, 24 yrs, 185 lb_f, manual lap belt restraint not used.

Vehicle 2: Driver, female, 19 yrs, 100 lb_f, manual lap+shoulder restraint not used.
Right front passenger, female, 14 yrs, 95 lb_f, manual lap+shoulder restraint not used.

DAMAGE:

Vehicle 1:
Location: Right side of front end
Direction of force: 12 o'clock direction
Deformation: Surface scratches and dents on right half of bumper and grill. Sheet metal of right front fender is buckled. Sheet metal of engine hood is scratched. No integrity loss.
Intrusion: No intrusion
Ejection: None

Vehicle 2:
Location: Right side
Direction of force: 2 o'clock direction
Deformation: Direct damage to passenger door. Passenger door has opened. A-pillar, B-pillar and roof side rail are pushed inward. Right front fender is dented and scratched and shows evidence of tire marks. Engine hood is buckled. Right door sill under A-pillar is pushed inward. Integrity loss through passenger door.
Intrusion: Maximum intrusion to passenger side door greater than 15 cm.
Ejection: None.

ΔV:

Vehicle 1: Not calculated.

Vehicle 2: Not calculated.

INJURIES:

Vehicle 1: Driver: not injured

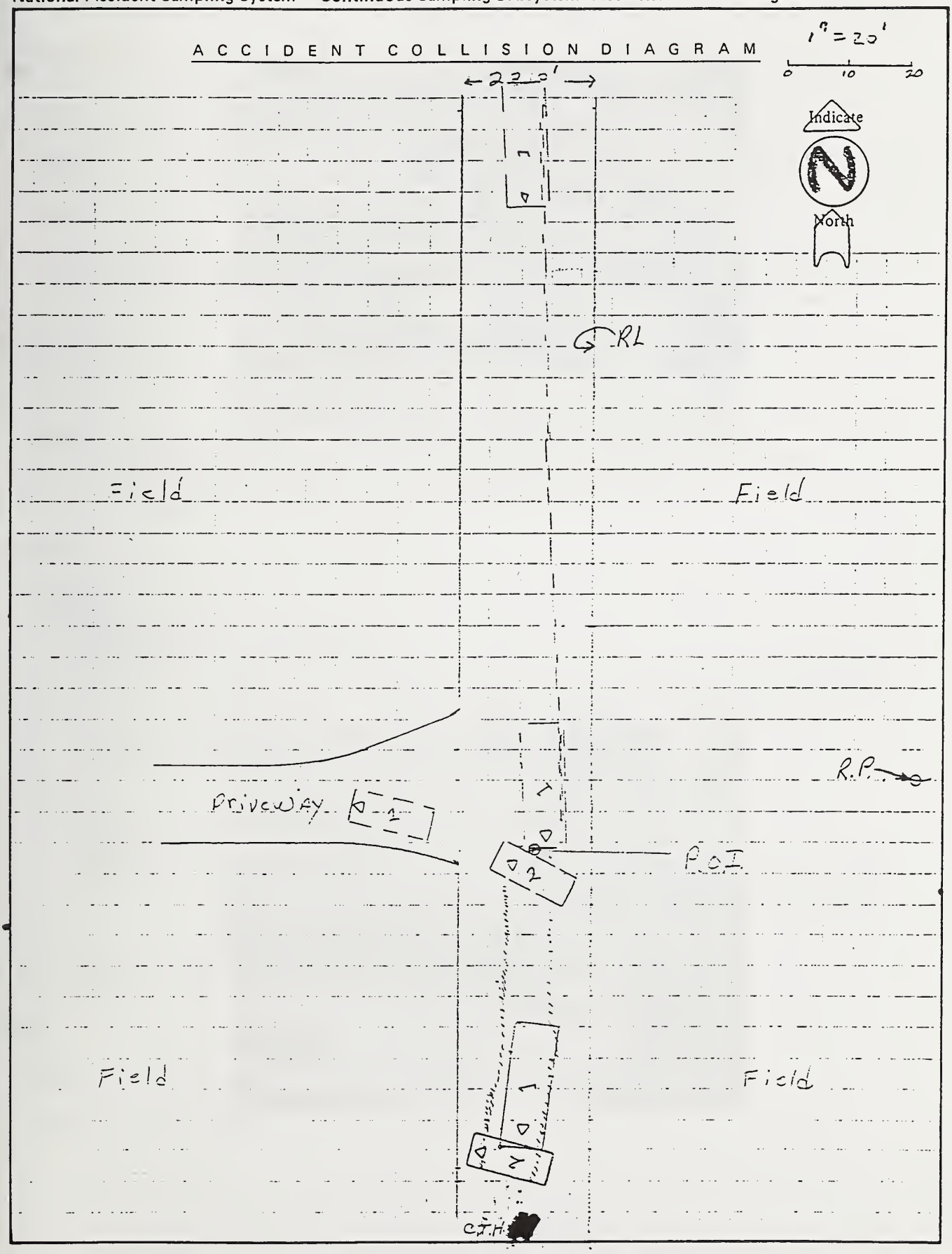
Vehicle 2: Driver: transported and released, contusion on upper back - ais 1, abrasions on upper back - ais 1, abrasions on right forearm - ais 1.
Passenger: hospitalized for six days, fractured pelvis - ais 2, fractured right fibula - ais 2, laceration on right cheek, forehead, and right ankle - ais 1.

INJURY MITIGATION AND COMMENTS:

The photographs indicate direct damage to vehicle 2 extending from the sill height up to the roof rail. Sill damage is most likely due to engagement with the truck's front tire. However, the photographs also indicate that sill override did not occur.

Although a considerable amount of occupant compartment intrusion occurred, it seems probable that engagement of the roof side rail with the truck's engine hood provided increased stiffness. Softening the truck's front-end would have likely decreased occupant intrusion to vehicle 2 further. However, the accident diagram indicates that due to the angle at which vehicle 2 was hit, a deflecting structure on the truck's front-end may increase the severity of impact by reducing the area over which the load is absorbed.

National Accident Sampling System — Continuous Sampling Subsystem: Accident Collision Diagram



YEAR: 1983
PSU: 27
CASENO: 150
NATWGT: 92.3

ACCIDENT DESCRIPTION:

Vehicle 1: '79 GMC Astro 95 Royal Classic truck pulling one trailer, 14577 lb_f, 1 occupant.

Vehicle 2: '81 AMC Eagle Kammback 4x4, 3-door hatchback, 3132 lb_f, 4 occupants.

Vehicle 1, traveling eastbound on a 4-lane divided highway (speed limit 40 mph) attempts a left-hand turn onto an on ramp and hits vehicle 2, traveling westbound and attempting a right-hand turn onto the on ramp, in the front left side. police reports indicate vehicle 1 traveling at 15 mph and vehicle 2 traveling at 40 mph.

OCCUPANTS:

Vehicle 1: Driver, male, 36 yrs, manual lap+shoulder restraint not used.

Vehicle 2: Driver, male, 23 yrs, 130 lb_f, manual lap+shoulder restraint not used.
Right front passenger, female, 16 yrs, 165 lb_f, manual lap+shoulder restraint not used.
Left rear passenger, male, 23 yrs, 185 lb_f, manual lap belt not used.
Right rear passenger, female, 23 yrs, 140 lb_f, manual lap belt not used.

DAMAGE:

Vehicle 1:
Location: Right half of front end
Direction of force: 1 o'clock direction
Deformation: Surface scratches and dents on bumper and grill. Evidence of red paint from vehicle 2 on bumper. Frame bent at bumper mount. Sheet metal is buckled at right front corner just above bumper. Headlight is missing due to impact. No integrity loss.
Intrusion: No intrusion
Ejection: None

Vehicle 2:
Location: Front half of left side
Direction of force: 10 o'clock direction
Deformation: Direct damage from front end back to driver door. Driver door has opened. A-pillar is pushed inward and roof side rail pushed upward. Hood and engine have been pushed back and inward. Bumper has been detached. integrity loss through driver door and front windshield.
Intrusion: Maximum intrusion through driver compartment area greater than 15 cm.
Ejection: None.

ΔV:

Vehicle 1: Not calculated.

Vehicle 2: Not calculated.

INJURIES:

Vehicle 1: Driver: not injured

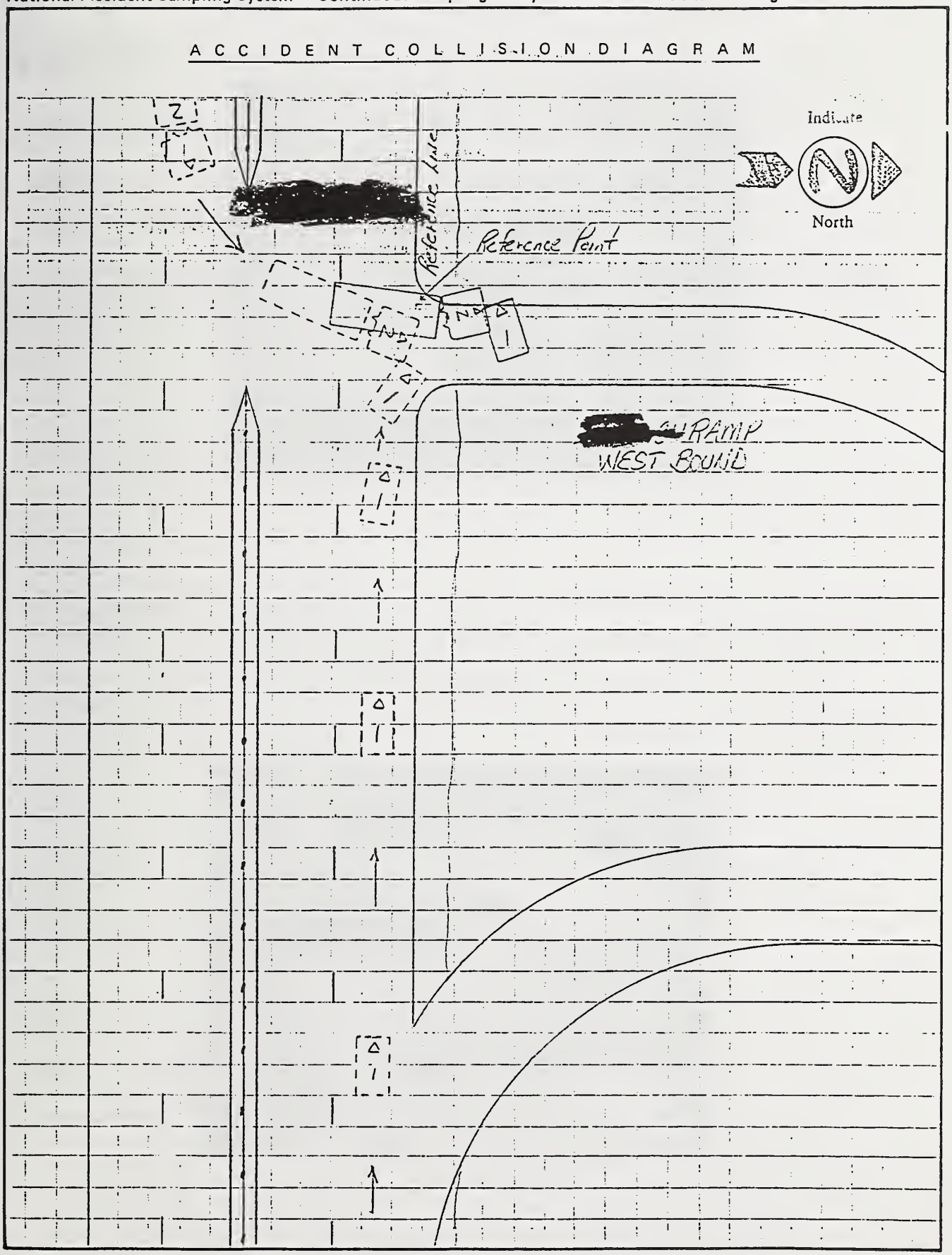
Vehicle 2: Driver: hospitalized, right wrist fractured and dislocated - ais 3, fractured ribs - ais 3, head concussion - ais 2, facial lacerations - ais 1,
Right front passenger: hospitalized for seven days, head concussion - ais 1, left leg contusion and abrasions - ais 1.
Left rear passenger: hospitalized for 1 day, head concussion - ais 1, contusion on chest - ais 1.
Right rear passenger: hospitalized for six days, skull fracture - ais 3, fractured jaw - ais 3, head concussion - ais 2, facial lacerations - ais 1.

INJURY MITIGATION AND COMMENTS:

The damage to vehicle 2 was very severe. Most of the occupant compartment intrusion occurred in the driver area, but there does not appear to be any indication of sill override, indicating that geometric mismatch was not the major basis for the damage. It is more likely that the truck's stiffer characteristics contributed to the extent of damage. A softer front-end may have provide greater protection to the occupants of vehicle 2.

The accident collision diagram indicates that vehicles remained together after initial contact until coming to rest. Due to the vehicles' areas where contact first occurred, it is reasonable to think that a structure on the truck's front-end may produce the effect of deflecting the struck vehicle out of the truck's path and is likely to reduce the amount of intrusion to vehicle 2.

National Accident Sampling System – Continuous Sampling Subsystem: Accident Collision Diagram



YEAR: 1984
PSU: 55
CASENO: 262
NATWGT: 116.0

ACCIDENT DESCRIPTION:

Vehicle 1: '70 AMC Hornet, 4 door sedan, CW = 2814 lbs, 1 occupant

Vehicle 2: '83 Piearce Dash firetruck, GVW = 37180 lbs, 4 occupants

At a multi-lane intersection (speed limit 45 mph), vehicle 1 travelling west was impacted by vehicle 2 travelling south. Vehicle 2 then impacted vehicle 3 (not described). Vehicle 2's left frontal region impacted the right side (frontal region) of vehicle 1.

OCCUPANTS:

Vehicle 1: Driver: male, 35 yrs, 190 lbs, unrestrained

Vehicle 2: Driver: no information available
Passenger: no information available

DAMAGE:

Vehicle 1:
Location: Right side (frontal region)
Direction of Force: 3 o'clock
Deformation: The average crush was approximately 14". The front bumper was overridden. The frontal structure above the bumper was pushed back. The windshield was cracked.
Intrusions: There was intrusion through the floorboard (> 6").
Ejections: None
Contact locations: There was occupant contact with the steering assembly, instrument panel, rearview mirror, and sunvisor.

Vehicle 2:
Location: Front
Direction of Force: 12 o'clock
Deformation: Left front bumper was bent backwards and right front bumper sustained a dent.
Intrusion: None
Ejections: None
Contact locations: None

ΔV:

Vehicle 1: Not calculated

Vehicle 2: Not calculated

Approach velocity = Not calculated

INJURIES:

Vehicle 1: Driver sustained a concussion (AIS 4), possibly due to contact with the steering assembly.

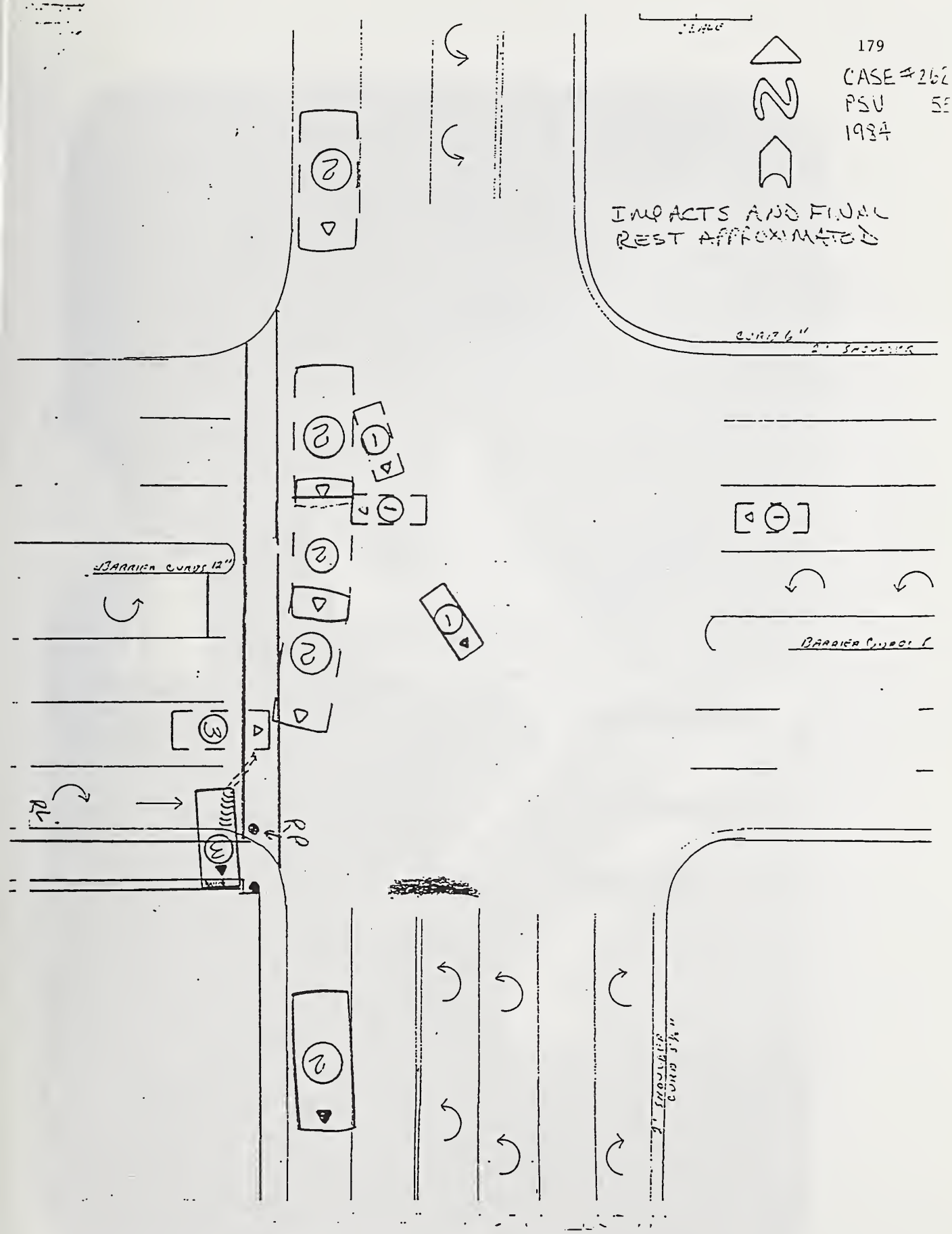
Vehicle 2: No injuries were listed.

INJURY MITIGATION AND COMMENTS:

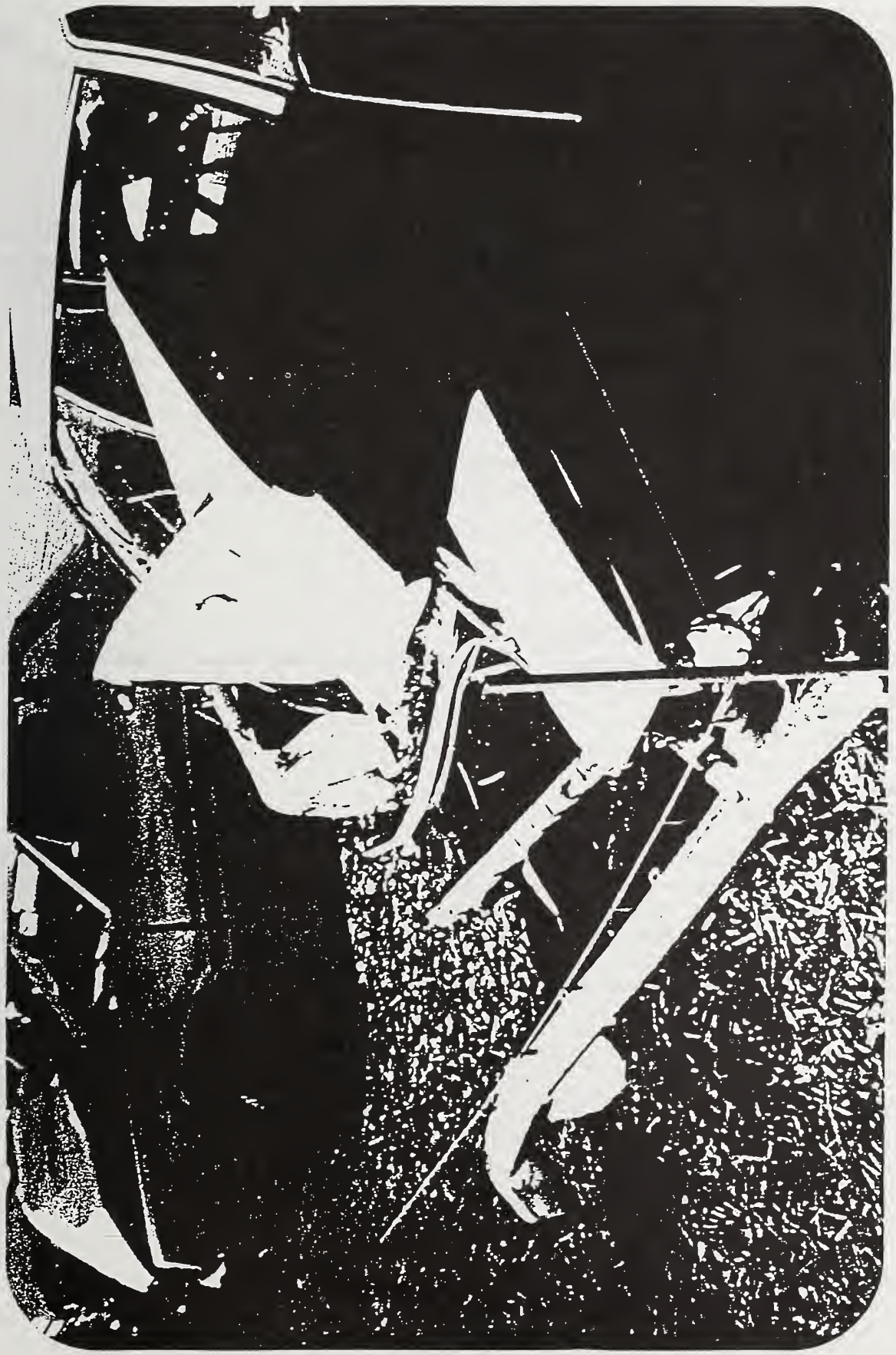
In this case, a modified truck bumper which is lower and softer may have been a benefit. The bumper geometric modification would have prevented the bumper override and would have allowed the vehicle to absorb more of the energy along with the compliant bumper. This would have resulted in less compartment intrusion and may have mitigated the driver injury.

CASE #262
PSU 55
1984

IMPACTS AND FINAL
REST APPROXIMATED



FIRE
DEPARTMENT



YEAR: 1984
PSU: 12
CASENO: 50
NATWGT: 147.4

ACCIDENT DESCRIPTION:

Vehicle 1: '75 single unit, two axle GMC 6500 truck, 10,500 lb_f, 1 occupant.

Vehicle 2: '80 Ford F20 custom pickup truck, 2 door, 3761 lb_f, 2 occupants.

Vehicle 2 attempts to make a left-hand turn onto a 2 lane road (speed limit 25 mph) and crosses into path of oncoming vehicle 1. Left, front bumper of vehicle 1 strikes vehicle 2 in the passenger side door at the A-pillar in a glancing blow type of collision causing vehicle 2 to rotate counterclockwise. Vehicle 2 rolls over onto roof and comes to rest. Travel speeds are unknown.

OCCUPANTS:

Vehicle 1: Driver, male, 31 yrs, 210 lb_f, manual lap belt restraint not used.

Vehicle 2: Driver, male, 29 yrs, 185 lb_f, manual lap+shoulder restraint not used.
Right front passenger, female, 24 yrs, 118 lb_f, manual lap+shoulder restraint not used.

DAMAGE:

Vehicle 1:
Location: Left, front end
Direction of force: 12 o'clock direction
Deformation: Left, front bumper and fender dented inward less than 5 inches. Surface scratches on left side of grill. No integrity loss.
Intrusion: No intrusion
Ejection: None

Vehicle 2:
Location: Right side
Direction of force: 4 o'clock direction
Deformation: Direct damage to right side from front fender to end of vehicle. Maximum direct damage occurring in passenger door just below A-pillar. Door sill engaged and pushed inward. Right front windshield cracked from impact. Direct damage to roof and rear left side from rollover. Integrity loss to right side door. A-pillar bent inward possibly as a result from rollover.
Intrusion: Intrusion to right side door greater than 15 cm.
Ejection: None

ΔV:

Vehicle 1: Not calculated.

Vehicle 2: Not calculated.

INJURIES:

Vehicle 1: Driver not injured.

Vehicle 2: Driver: Lumbar spine contusion and sprain - ais 3, hip contusion - ais 2, lower back muscle spasms - ais 1. Hospitalized for 12 days.

Passenger: Cerebral concussion - ais 4, fractured left hand - ais 1, lacerated left thumb - ais 1, right shoulder contusion - ais 1.

INJURY MITIGATION AND COMMENTS:

This case demonstrates a better geometric match by the vehicles in that vehicle 1 appears to have engaged the sill of vehicle 2, possibly preventing a greater amount of intrusion. It is difficult to support this conclusion, however, when vehicle speeds and ΔV calculations are unknown. The truck's bumper sustained very little damage which suggests that softening this structure may reduce the severity of crush to the other vehicle. Finally, evidence from the accident case does not indicate the effects of a deflecting structure on the truck's front end.

Delete Street Names After Case Review

Delete Street Names After Case Review

YEAR: 1984
PSU: 55
CASENO: 189
NATWGT: 110.3

ACCIDENT DESCRIPTION:

Vehicle 1: '79 Mack medium/heavy truck, COE, 14500 lb_f, 2 occupant.

Vehicle 2: '78 Dodge, 2-door sedan, hardtop, 3800 lb_f, 3 occupants.

Right front corner of vehicle 1 strikes vehicle 2 in right side of passenger compartment area. Vehicle 1 is reported traveling at 35 mph and vehicle 2 at 20 mph. No other information is available about the details of the accident.

OCCUPANTS:

Vehicle 1: Driver, male, 19 yrs, 185 lb_f, manual lap belt restraint not used.

Vehicle 2: Driver, female, 23 yrs, 190 lb_f, manual lap+shoulder restraint not used.
Right front passenger, male, 20 yrs, 170 lb_f, manual lap+shoulder restraint not used.
Right rear passenger, male, 21 yrs, 150 lb_f, manual lap belt restraint not used.

DAMAGE:

Vehicle 1:
Location: Right side of front end
Direction of force: 11 o'clock direction
Deformation: Surface scratches and dents on right half of bumper. Sheet metal above right front fender and around right headlight is dented. No integrity loss.
Intrusion: No intrusion
Ejection: None

Vehicle 2:
Location: Right side
Direction of force: 2 o'clock direction
Deformation: Extensive damage to vehicle. Direct damage to passenger compartment area. Right A, B, and C-pillar and passenger door completely torn away. Roof pushed inward. Right door sill crushed down and inward. Integrity loss through passenger door and front and back windshield.
Intrusion: Maximum intrusion to passenger side door greater than 15 cm.
Ejection: None.

ΔV:

Vehicle 1: Not calculated.

Vehicle 2: Not calculated.

INJURIES:

Vehicle 1: Driver: not injured

Vehicle 2: Driver: transported and released, laceration on right forearm and wrist - ais 1.
Right front passenger: hospitalized for twenty days, cerebral concussion - ais 5, fractured right forearm - ais 2, facial lacerations - ais 1.
Right rear passenger: transported and released, right shoulder laceration-ais 1.

INJURY MITIGATION AND COMMENTS:

The damage to vehicle 2 is very severe. The crushed door sill on vehicle 2 is most likely due to contact with the truck's front tires since the truck's front bumper is well above the height of the passenger car sill. The geometric mismatch, therefor, resulted in sill override. This may have been avoided had the truck's bumper engaged the door sill. Lower stiffness characteristics on the truck's front-end may have decreased the severity as well.

There is not enough evidence from the case study to support the conclusion that a deflective structure on the truck's front-end would have deflected the passenger car out of the moving truck's path, decreasing the impact severity.

YEAR: 1984
PSU: 54
CASENO: 102
NATWGT: 102.8

ACCIDENT DESCRIPTION:

Vehicle 1: '71 Ford Torino GT, 2 door coupe CW=3380 lbs, 1 occupant

Vehicle 2: '79 Kenworth K100 COE w/trailer, GVW > 33000 lbs, 1 occupant

On a 3-lane roadway (speed limit 45 mph), vehicle 2 was proceeding east. Vehicle 1 (not described) tried to pass vehicle 2, but impacted it on its left side. Vehicle 2 tried to maintain control but swerved in front of the vehicle 3, which was heading west. Vehicle 3 impacted vehicle 2 on its right side (center region).

OCCUPANTS:

Vehicle 1: Driver: male, 62 yrs, 195 lbs, unrestrained

Vehicle 2: Driver: no information available

DAMAGE:

Vehicle 1:
Location: Side (center region)
Direction of Force: 3 o'clock
Deformation: This vehicle sustained sever damage. The average side crush was approximately 37". Vehicle 2 was wrapped around vehicle 3. Vehicle 2 was bowed inward abut half the width of the car. The compartment integrity was lost through the windshield and the side door.
Intrusions: Occurred through the right side of the vehicle.
Ejections: The drive was ejected through the left front door.
Contact locations: There was contact with the instrument panel, the side hardware or armrest, the roof, side rails, and surface exterior to the vehicle.

Vehicle 2:
Location: Front
Direction of Force: 12 o'clock
Deformation: Sustained damage to the bumper and grille area. The right headlight was broken.
Intrusion: None
Ejections: None
Contact locations: There was occupant contact with the steering assembly, instrument panel and below, sunvisor, and side hardware or armrests

ΔV:

Vehicle 1: Not calculated

Vehicle 2: Not calculated

Approach velocity = approximately 30 mph (based on truck driver interview)

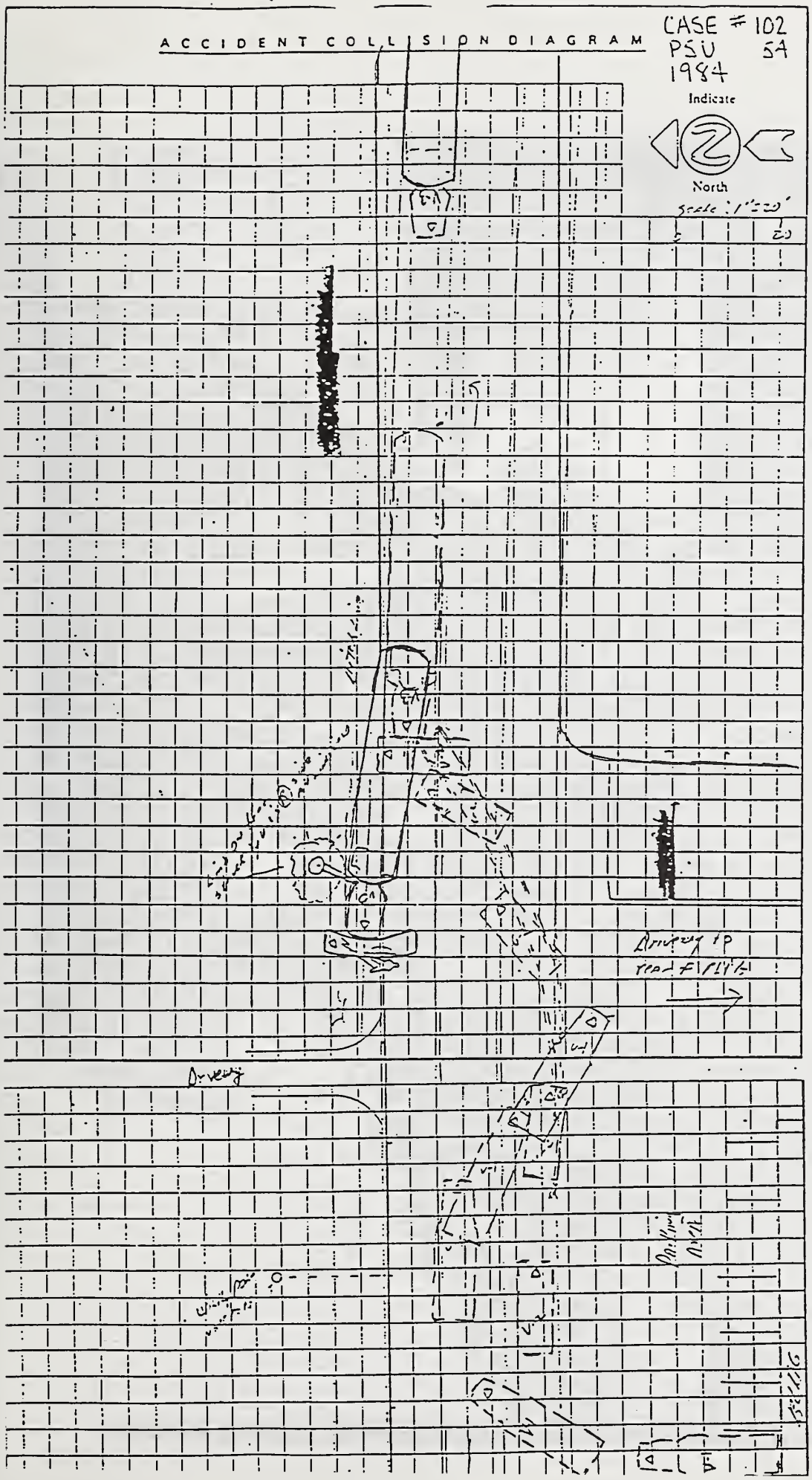
INJURIES:

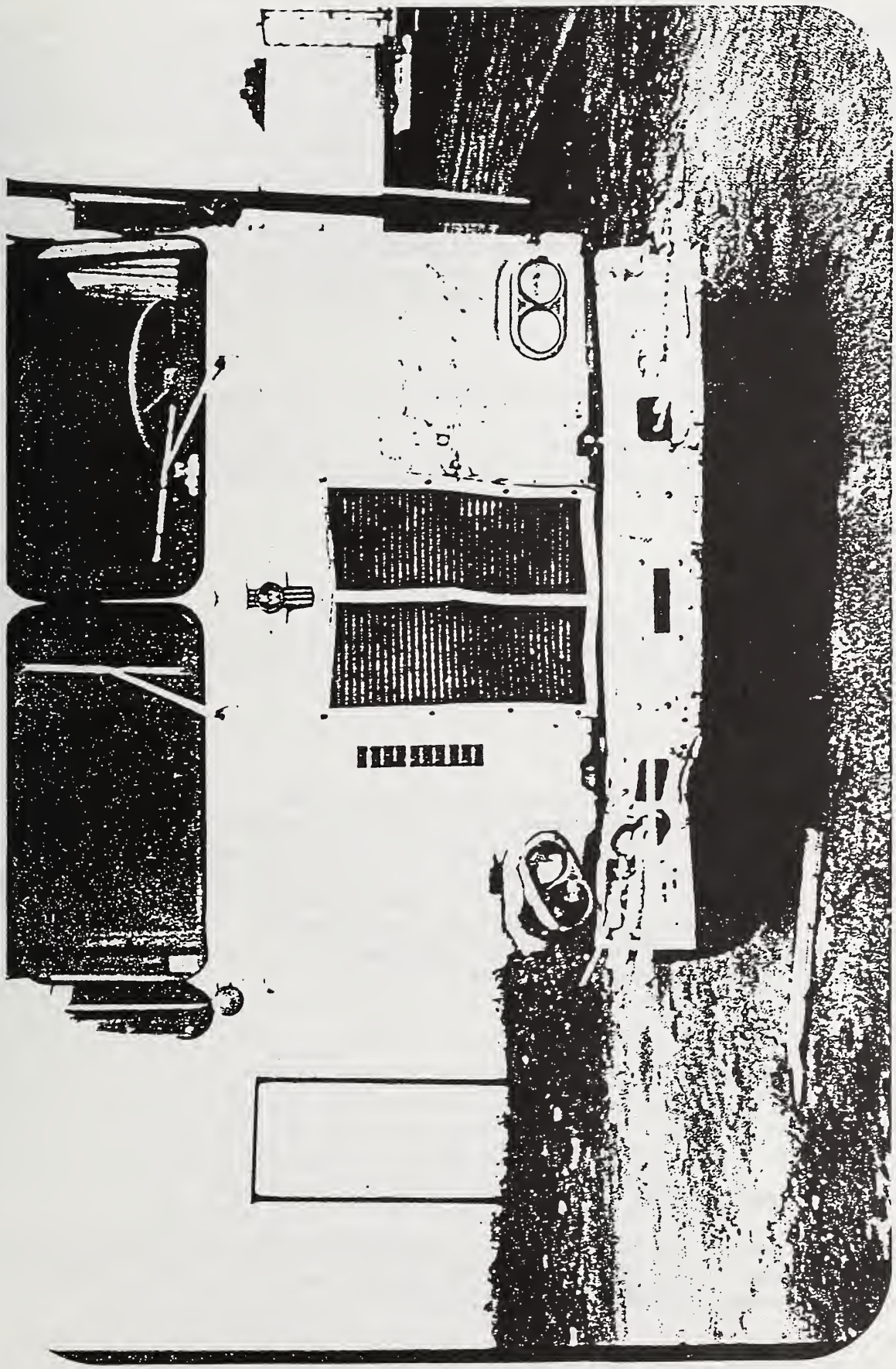
Vehicle 1: The driver was killed. He sustained massive trauma to the right side of the head, possibly due to the contact with the roof side rail or some exterior surface outside of the vehicle. His right front chest was also crushed possibly due to contact with the side hardware.

Vehicle 2: The driver sustained bruises and abrasions to the left knee and thigh, respectively, possibly due to the contact with the knee panel. In addition the driver sustained a bruise to this forehead possibly due to the contact with the steering assembly.

INJURY MITIGATION AND COMMENTS:

Vehicle 2 sustained severe side damage with excessive compartment intrusion. It was observed that the door sill absorbed some of the energy imparted by the truck. Based on these observations, it was concluded that a modified truck bumper would not have mitigated the occupant injury response or the amount of vehicle damage.


ACCIDENT COLLISION DIAGRAM
CASE # 102
PSU 54
1984
Indicate
North
Scale: 1"=20'
Driveway
Driveway



YEAR: 1984
PSU: 32
CASENO: 161
NATWGT: 23.2

ACCIDENT DESCRIPTION:

Vehicle 1: '79 Ford CLT 9000 truck with no cargo trailer, 13,500 lb_f, 1 occupant.

Vehicle 2: '83 Dodge Aries, 4 door sedan, 2327 lb_f, 2 occupants.

Vehicle 2 attempts to make a left-hand turn onto a 4 lane road (speed limit 40 mph) and crosses into path of oncoming vehicle 1. Vehicle 1 strikes vehicle 2 on left side causing vehicle 2 to rotate nearly 270 degrees and strike a third vehicle with its front end. Driver of vehicle 2 is ejected. Travel speeds are unknown.

OCCUPANTS:

Vehicle 1: Driver, male, 25 yrs, 240 lb_f, no manual or automatic restraint system available.

Vehicle 2: Driver, female, 17 yrs, 95 lb_f, manual lap+shoulder restraint not used.
Right front passenger, male, 17 yrs, 150 lb_f, manual lap+shoulder restraint not used.

DAMAGE:

Vehicle 1:
Location: Front end
Direction of force: 12 o'clock direction
Deformation: Light surface scratches and minor dents across front bumper and grill. Front grill loosened.
Intrusion: No intrusion
Ejection: None

Vehicle 2:
Location: Left side (from vehicle 1); front end (from third vehicle)
Direction of force: 9 o'clock direction (from vehicle 1); 12 o'clock direction (from third vehicle)
Deformation: Direct damage to left side beginning 43" behind front axle to end of vehicle. Direct damage along entire height of vehicle. Maximum intrusion occurring at mid-door height. Door sill does not appear to have been fully engaged. Front left door integrity loss. Minor damage to front bumper from second impact.
Intrusion: Maximum intrusion to left side doors less than 15 cm.
Ejection: Driver completely ejected through left front door.

ΔV:

Vehicle 1: Not calculated.

Vehicle 2: Not calculated.

INJURIES:

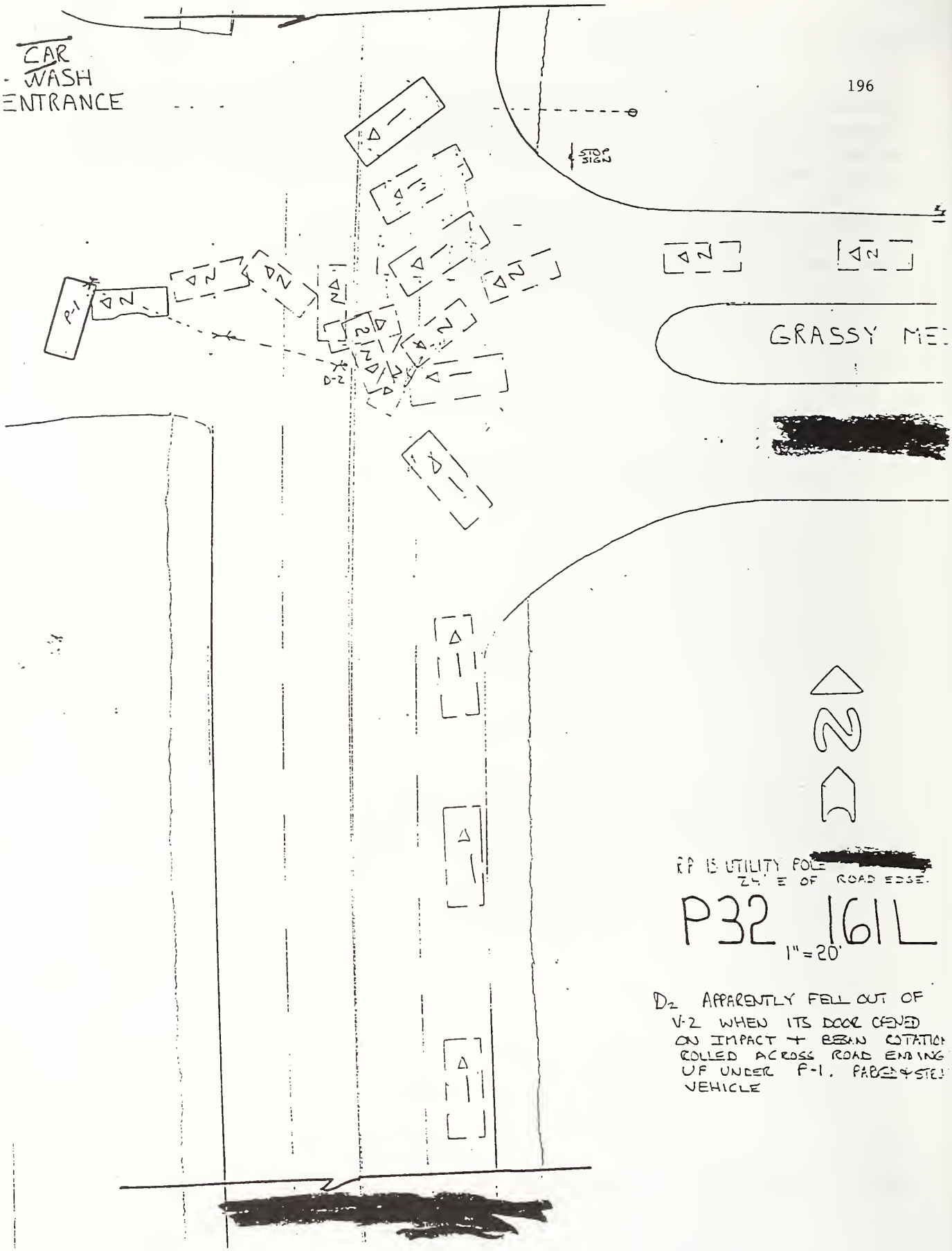
Vehicle 1: Driver: not injured.

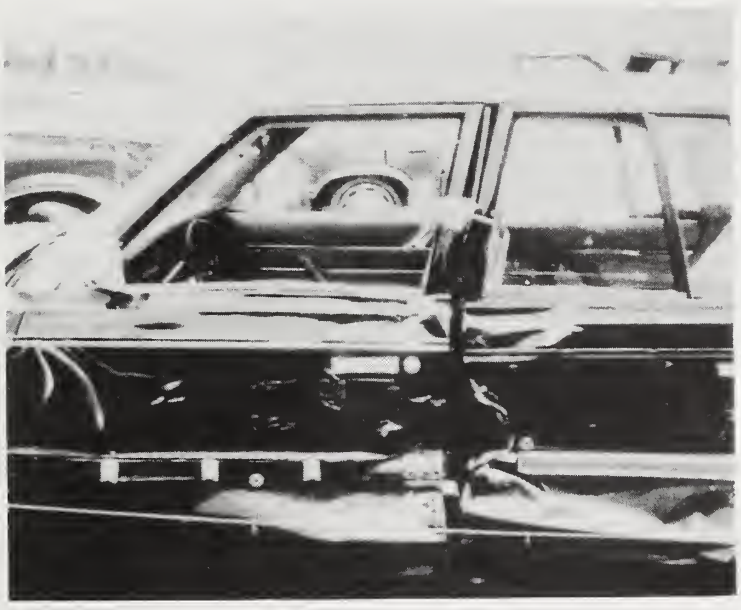
Vehicle 2: Driver: Cerebral concussion - ais 2, contusion to back of head - ais 1, right and left knee abrasions - ais 1, right and left upper arm abrasions - ais 1.
Passenger: Cerebral concussion - ais 2.

INJURY MITIGATION AND COMMENTS:

The trunk's front bumper appears to have caused the maximum intrusion at mid-door level and photographs give no evidence of contact to the passenger car sill. Although there is very little intrusion to the occupant compartment, it is likely that even less would have occurred had the front bumper engaged the car sill, offering more structural stiffness to the impact. Likewise, lower stiffness characteristics in the truck's front-end would decrease the severity of the impact as well.

In this case, the small amount of occupant intrusion may be partially attributed to the fact that the truck's entire front end was involved in the impact in which the load was distributed over a greater area. It appears that any deflecting structure an the truck's front-end may, in fact, increase the severity of impact for this case.


CAR
WASH
ENTRANCE
STOP SIGN
GRASSY ME
P-1
D-2
RP IS UTILITY POLE
24' E OF ROAD EDGE.
P32 161L
1" = 20'
D2 APPARENTLY FELL OUT OF V-2 WHEN ITS DOOR OPENED ON IMPACT + BEGAN ROTATION ROLLED ACROSS ROAD ENDING UP UNDER P-1. PASSENGER STEEL VEHICLE



APPENDIX A
CRASH3 Damage Algorithm

A.1 INTRODUCTION

The CRASH3 computer program is used to estimate the velocity change ($\Delta V'$) of vehicles in the approach phase of a collision. The computer program uses the damage algorithm as one of the methods to estimate the change in velocity (or $\Delta V'$) during the approach period in an accident. The algorithm uses the damage measurements of vehicles involved in an accident to estimate the approach energy, which is used to estimate the $\Delta V'$ by using conservation of momentum.

A.2 THEORY AND BACKGROUND

A.2.1 Equations For ΔV

The equations used by CRASH3 to calculate ΔV for the most general collision configuration (non-central,oblique) are described in brief. A complete discussion and derivation of these expressions appear in the CRASH3 Technical Manual [1]. The final equations, along with the underlying assumptions, and the governing physical laws are presented below.

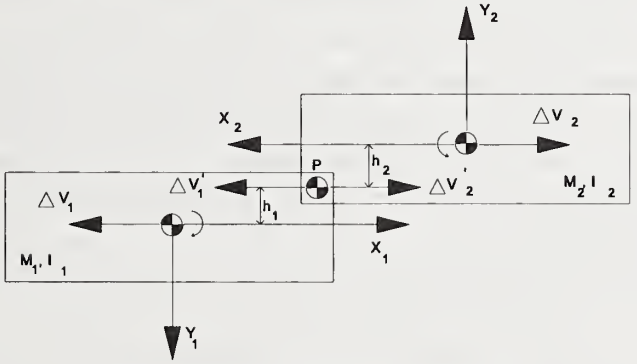


Fig.A.1 Non-central Collisions.

In the general case of non-central collisions, a common velocity is assumed to be achieved at some point P in the region of contact (see Fig.A.1). For such a situation, the change in velocity at the center of gravity during the approach period can be shown to be:

$$\Delta V_1 = (1+\epsilon) \cdot \sqrt{\frac{2 \times \gamma_1 \times E_A}{M_1 \times \left(1 + \frac{\gamma_1 \times M_1}{\gamma_2 \times M_2}\right)}} \qquad \text{(A.1)}$$

and

$$\Delta V_2 = (1+\epsilon) \cdot \sqrt{\frac{2 \times \gamma_2 \times E_A}{M_2 \times \left(1 + \frac{\gamma_2 \times M_2}{\gamma_1 \times M_1}\right)}} \quad \textbf{(A.2)}$$

where

$$\gamma_1 = \frac{k_1^2}{k_1^2 + h_1^2} \quad \textbf{(A.3)}$$

$$\gamma_2 = \frac{k_2^2}{k_2^2 + h_2^2} \quad \textbf{(A.4)}$$

k_1 and k_2= Radius of gyration of Vehicles 1 and 2
h_1 and h_2= Moment arm of impact forces
ΔV_1= Total change in velocity of Vehicle 1
ΔV_2= Total change in velocity of Vehicle 2
E_A = Total energy dissipated during approach period (vehicle 1 and 2)
M_1= Mass of Vehicle 1
M_2= Mass of Vehicle 2
ϵ= Coefficient of restitution for the impact between the two vehicles
The approach period referred to above is the time between initial contact and the time when maximum crush occurs. The velocities of the two vehicles are assumed to be equal at the moment of maximum crush. Similarly, the separation period is the period between the maximum crush and complete separation of the vehicles. The total change in velocity is the change during approach period added to the change during the separation period. The current model calculates approach velocity change only. The changes in velocity during the approach period (as calculated by the present CRASH3) are given by:

$$\Delta V_1' = \sqrt{\frac{2 \times E_A \times M_2}{M_1 \times (M_1 + M_2)}} \quad \textbf{(A.5)}$$

$$\Delta V_2' = \sqrt{\frac{2 \times E_A \times M_1}{M_1 \times (M_1 + M_2)}} \quad \textbf{(A.6)}$$

It should be noted that the radius of gyration used in CRASH3a is based on investigations done

$$k = 0.3 \times (vehiclelength) \quad \textbf{(A.7)}$$

at V.R.T.C. as a part of the Crash Avoidance Inertial Parameter Measurement Program [4]. The moment arm of the impact forces i.e., h_1 and h_2 can be obtained from geometrical considerations and depends on the location of the centroid of the damaged area relative to the vehicle center of gravity, and the principal direction of force (PDOF). The details of the procedure to determine h_1 and h_2 can be found in the CRASH3 Technical Manual [1].

A.2.2 Obtaining Crush Energy E_A

An important assumption of the damage algorithm is that the energy dissipated during the approach period i.e., the term E_A appearing in equations (A.1) and (A.2) can be approximated using residual crush measurements. The calculation is based on the work done by Campbell [3] in which a linear relationship was observed between static crush and impact speed into a fixed rigid barrier. Further crash tests and analysis indicate a linear relationship between the quantity $\sqrt{\frac{2E_A}{w}}$ (i.e., square root of twice the energy absorbed per unit crush width in the approach period) and residual crush (see [2] and [3] for details). The equation describing this relationship is:

$$\sqrt{\frac{2\times E_A}{w}} = d_0 + d_1 \times C$$

The energy absorbed by the vehicle in the approach period can therefore be calculated by using this linear relationship and integrating across the crush profile. The results are [2]:

$$E_A = K_1 \times d_0^2 + K_2 \times d_0 \times d_1 + K_3 \times d_1^2 \qquad \textbf{(A.10)}$$

where

$$\left.\begin{aligned} K_1 &= \frac{W}{2} \\ K_2 &= \frac{W}{10}\left\{C_1 + 2(C_2 + C_3 + C_4 + C_5) + C_6\right\} \\ K_3 &= \frac{W}{30}\left\{C_1^2 + 2(C_2^2 + \cdots + C_5^2) + C_6^2 + C_1C_2 + C_2C_3 + \cdots + C_5C_6\right\} \end{aligned}\right\} \qquad \textbf{(A.11)}$$

In the above equations, the values of K_1,K_2, and K_3 are determined from the measured crush geometry, (see Fig.A.2) and d_0 and d_1 are vehicle crush parameters determined from a table of vehicle properties. This table is determined by crash test results or by estimating crash test performance using regression equations (see [2] and [3] for details). The CRASH3 stiffness coefficients A and B (intercept and slope of force per unit crush-width vs. crush) can be obtained from:

$$\begin{aligned} A &= d_0 d_1 \\ B &= d_1^2 \end{aligned} \qquad \textbf{(A.12)}$$

The values of d_0 and d_1 for the various vehicle makes and models are reproduced below:

A.3 d_0 AND d_1 FOR VEHICLES IN DATABASE

The following Tables contain the intercept d_0 and slope d_1 of the $\sqrt{(2E_A)/w}$ vs. residual crush for front,

procedure for obtaining these values have been described in Ref [1] and [2]. The units for the values are as follows:

d_0: $\sqrt{Newton}$ and d_1: $\frac{\sqrt{Newton}}{cm}$

The use of these values in equations (A.10) and (A.11) above with the values of crush $C_1..C_6$ in centimeters, and crush width W in meters, would give us ΔV in meters/sec.

The description for the body types can be found in Reference [1].

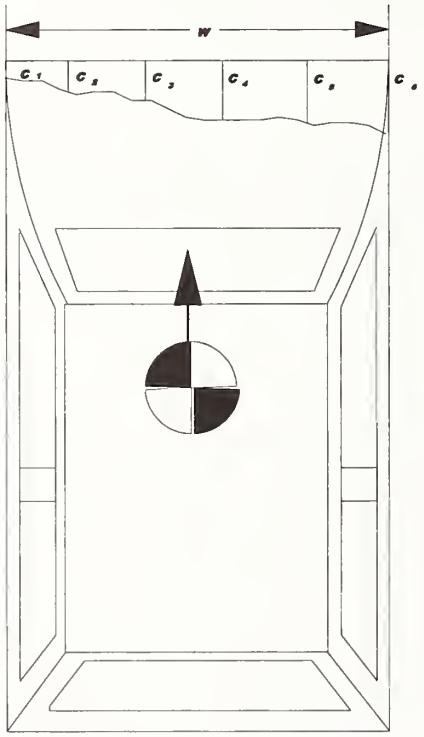


Fig.A.2 Crush Profile Approximation

A.4 MODIFICATION OF ΔV FOR HEAVY TRUCK TESTS

The above algorithm is not normally used by the Agency in accidents involving heavy trucks. This is because of the many assumptions of the damage algorithm. The principal one is that the energy absorbed by both vehicle structures must be considered in the ΔV equations. However, because of lack of proper documentation of the truck damage in the NASS files, and not having estimates of truck structural stiffness, the energy absorbed by the truck was ignored in the ΔV calculations.

After conducting six crash tests, with known values of ΔV of both vehicles (from on-board instrumentation as well as momentum calculations), the appropriate correction factor to account for the energy absorbed by the truck (and other factors) was calculated. This was done by calculating

the energy absorbed by the truck (and other factors) was calculated. This was done by calculating the ΔV by the CRASH3 damage algorithm using the damage information on the passenger car, and comparing it with the ΔV from the instruments and momentum calculations. Separate analyses were done for the straight line and for the angled impacts. The results are as follows:

$$\left.\begin{aligned} Avg\left(\frac{(\Delta V_{momentum})}{(\Delta V_{CRASH3})}\right) &= 1.665 \\ Std.Dev\left(\frac{(\Delta V_{momentum})}{(\Delta V_{CRASH3})}\right) &= 0.447 \\ Avg\left(\frac{(\Delta V_{instruments})}{(\Delta V_{CRASH3})}\right) &= 1.652 \\ Std.Dev\left(\frac{(\Delta V_{instruments})}{(\Delta V_{CRASH3})}\right) &= 0.41 \end{aligned}\right\} \textit{For straight impacts}$$

and

$$\left.\begin{aligned} Avg\left(\frac{(\Delta V_{momentum})}{(\Delta V_{CRASH3})}\right) &= 1.78 \\ Std.Dev\left(\frac{(\Delta V_{momentum})}{(\Delta V_{CRASH3})}\right) &= 0.42 \\ Avg\left(\frac{(\Delta V_{instruments})}{(\Delta V_{CRASH3})}\right) &= 1.81 \\ Std.Dev\left(\frac{(\Delta V_{instruments})}{(\Delta V_{CRASH3})}\right) &= 0.41 \end{aligned}\right\} \textit{For all impacts}$$

Based on these results, a correction factor of 1.6 will be applied to the values of ΔV as calculated by using the damage information on the car alone. This assumes that the impact dynamics in actual accidents are similar to those in the six tests studied.

Table A.1 Front Impacts

Yr	Make	Model	Bd	d0	d1
78	AMERICAN	CONCORD	3H	101.89	7.12
78	AMERICAN	GREMLIN	2S	97.44	6.56
78	BUICK	CENTURY	2C	103.39	5.69
78	BUICK	LESABRE	2S	108.90	4.86
78	CHEVROLET	CHEVETTE	3H	90.58	5.50
78	CHEVROLET	MONTE CARLO	2S	113.98	6.23
78	CHEVROLET	NOVA	4S	106.51	6.66
78	CHRYSLER	LE BARON	4S	108.03	7.27
78	DODGE	CHALLENGER	2C	95.18	5.15
78	DODGE	OMNI	5H	88.37	6.17
78	FORD	LTD	2C	112.08	4.26
78	MERCURY	MONARCH	2S	101.51	5.99
78	MERCURY	ZEPHYR	4S	96.79	6.53
78	NISSAN/DATSUN	810	SW	103.56	5.98
78	PEUGEOT	604	4S	104.34	7.22
78	PONTIAC	GRAND PRIX	2S	114.38	5.44
78	SUBARU	BRAT MPV	OT	99.66	5.49
78	TOYOTA	CRESSIDA	SW	106.87	5.93
78	VOLKSWAGEN	RABBIT	5H	100.79	5.44
79	BUICK	RIVIERA	2S	111.32	6.40
79	CHAMPION	MOTOR HOME	MH	123.41	8.08
79	CHEVROLET	CHEVETTE	5H	93.98	5.75
79	CHEVROLET	IMPALA	4S	105.12	6.27
79	CHEVROLET	MONZA	3H	99.78	5.66
79	CHEVROLET	PICKUP	PU	126.41	6.63
79	CHEVROLET	SPORTVAN	VN	121.54	8.78
79	CHINOOK	MOTOR HOME	MH	113.62	7.10
79	CHRYSLER	LE BARON	2C	106.64	6.25
79	DODGE	COLT PICKUP	PU	102.52	7.60
79	DODGE	MAGNUM	2S	107.57	5.73
79	DODGE	ST. REGIS	4S	107.50	5.37
79	FORD	COURIER	PU	117.38	7.35
79	FORD	FAIRMONT	4S	96.64	5.66
79	FORD	FIESTA	2S	83.75	5.42
79	FORD	GRANADA	4S	103.56	6.11
79	FORD	LTD	2S	113.77	5.39
79	FORD	MUSTANG	2C	92.63	6.82
79	HONDA	CIVIC	2S	85.94	5.88
79	JEEP	CHEROKEE MPV	SW	119.95	8.46
79	LINCOLN	CONTINENTAL	4S	116.13	5.75
79	MAZDA	PICKUP	PU	102.84	6.95
79	MERCURY	BOBCAT	3H	94.97	7.26
79	MERCURY	CAPRI	3H	95.20	5.39
79	MERCURY	MARQUIS	2S	106.74	5.42
79	NISSAN/DATSUN	210	2S	87.94	5.12
79	ODYSSEY	MOTOR HOME	MH	117.91	6.91
79	OLDSMOBILE	98	4S	111.58	5.76

Table A.1 Front Impacts(Contd.)

Yr	Make	Model	Bd	d0	d1
79	OLDSMOBILE	CUTLASS	2C	103.77	5.04
79	OLDSMOBILE	CUTLASS	2S	103.47	4.93
79	PLYMOUTH	CHAMP	3H	86.32	6.07
79	PLYMOUTH	HORIZON	3H	90.01	5.67
79	PLYMOUTH	VOLARE	2C	103.18	6.23
79	TOYOTA	CELICA	3H	97.08	6.22
79	TOYOTA	PICKUP	PU	100.54	9.06
79	VOLKSWAGEN	RABBIT	3H	90.77	5.95
79	VOLVO	244	4S	101.36	9.08
80	AMERICAN	CONCORD	2S	60.85	8.58
80	AMERICAN	EAGLE MPV	2S	113.71	7.62
80	AUDI	4000	4S	92.71	5.82
80	CADILLAC	SEVILLE	4S	113.96	6.40
80	CHEVROLET	CHEVETTE	3H	54.48	6.50
80	CHEVROLET	CHEVETTE	5H	55.43	6.54
80	CHEVROLET	CITATION	5H	52.90	6.43
80	CHEVROLET	LUV PICKUP	PU	103.37	9.42
80	CHRYSLER	LE BARON	2C	102.50	5.81
80	COMUTA	CAR ELECTRIC	2C	82.23	9.35
80	FIAT	STRADA	5H	91.49	4.59
80	FORD	BRONCO	UV	112.67	6.47
80	FORD	PICKUP	PU	101.70	6.53
80	FORD	THUNDERBIRD	2C	105.73	6.57
80	HONDA	PRELUDE	2C	91.34	5.63
80	MAZDA	626	2C	97.36	5.65
80	MERCEDES	240	4S	103.03	7.12
80	NISSAN/DATSUN	200 SX	3H	96.11	5.38
80	NISSAN/DATSUN	2000	3H	87.02	5.93
80	NISSAN/DATSUN	PICKUP	PU	102.15	7.93
80	OLDSMOBILE	CUTLASS	4S	103.26	5.43
80	SUBARU	GF	4S	90.54	5.74
80	SUBARU	GLF	4S	89.65	5.67
80	SUBARU	WAGON	SW	96.43	5.98
80	TOYOTA	PICKUP	PU	108.60	8.14
80	TOYOTA	TERCEL	2S	85.24	5.21
80	TOYOTA	TERCEL	3H	89.17	6.57
80	VOLKSWAGEN	RABBIT	OT	93.64	5.93
80	VOLKSWAGEN	VANAGON	OT	107.50	9.90
81	AMERICAN	CONCORD	2S	105.46	6.23
81	AMERICAN	SPIRIT	3H	94.21	6.01
81	CADILLAC	DE VILLE	4S	114.91	5.40
81	CHEVROLET	IMPALA	4S	104.80	5.75
81	CHEVROLET	PICKUP	PU	108.41	6.04
81	CHRYSLER	IMPERIAL	2C	121.20	5.54
81	DODGE	CHALLENGER	2C	99.53	6.33
81	DODGE	DIPLOMAT	4S	107.86	5.82
81	FORD	COURIER	PU	104.53	6.34

Table A.1 Front Impacts(Contd.)

Yr	Make	Model	Bd	d0	d1
81	FORD	ESCORT	3H	91.05	5.58
81	HONDA	CIVIC	3H	83.53	5.84
81	HONDA	CIVIC	4S	90.69	6.14
81	LECTRIC	LEAPARD	4S	106.72	4.76
81	MAZDA	GLC	5H	92.59	5.54
81	MERCURY	MARQUIS	2S	101.39	5.44
81	PLYMOUTH	RELIANT	2S	87.38	5.80
81	RENAULT	18	4S	91.15	4.98
81	SUBARU	WAGON	SW	96.72	6.18
81	TOYOTA	CRESSIDA	4S	106.45	6.54
81	TOYOTA	STARLET	3H	88.81	6.86
81	VOLKSWAGEN	JETTA	4S	99.30	5.98
82	BUICK	CENTURY	4S	90.29	5.95
82	CHEVROLET	CAMARO	2C	105.08	6.20
82	CHEVROLET	CAMARO	3H	88.49	5.54
82	CHEVROLET	CAVALIER	2C	97.36	6.96
82	CHEVROLET	CELEBRITY	4S	103.83	5.95
82	CHEVROLET	CHEVETTE	4S	84.86	5.30
82	CHEVROLET	CITATION	3H	84.93	4.81
82	CHEVROLET	CITATION	5H	100.37	6.38
82	CHEVROLET	LUV PICKUP	PU	103.66	6.74
82	CHEVROLET	PICKUP	PU	88.98	6.17
82	CHEVROLET	SPORTVAN	VN	95.71	9.99
82	CHRYSLER	LE BARON	OT	93.81	6.11
82	DODGE	400	2C	99.32	5.62
82	DODGE	OMNI	5H	90.31	5.57
82	DODGE	RAMPAGE	PU	97.55	6.62
82	FORD	ESCORT	3H	80.22	6.08
82	FORD	ESCORT	5H	93.35	5.75
82	FORD	GRANADA	4S	100.37	5.59
82	FORD	GRANADA	SW	107.95	5.87
82	FORD	LTD	4S	105.90	6.18
82	FORD	PICKUP	PU	87.80	8.03
82	FORD	VAN	VN	101.45	9.36
82	HONDA	ACCORD	3H	80.50	4.62
82	HONDA	ACCORD	4S	93.18	5.26
82	MAZDA	626	4S	94.40	6.62
82	NISSAN/DATSUN	SENTRA	4S	86.19	5.66
82	NISSAN/DATSUN	STANZA	4S	98.18	6.13
82	OLDSMOBILE	CUTLASS	2S	96.22	5.08
82	PLYMOUTH	RELIANT	2S	84.48	5.57
82	RENAULT	FUEGO	2C	99.42	6.05
82	RENAULT	FUEGO	3H	99.51	6.10
82	TOYOTA	CELICA	2C	102.27	6.28
82	TOYOTA	COROLLA	4S	84.10	5.52
82	TOYOTA	CORONA	4S	96.79	5.60
82	TOYOTA	LAND CRUISER	MP	139.91	10.98

Table A.1 Front Impacts(Contd.)

Yr	Make	Model	Bd	d0	d1
82	TOYOTA	PICKUP	PU	87.35	7.33
82	VOLKSWAGEN	QUANTUM	4S	98.98	6.35
82	VOLKSWAGEN	RABBIT	5H	97.40	5.64
82	VOLKSWAGEN	SCIROCCO	3H	91.72	5.83
82	VOLVO	DL	4S	103.41	5.44
82	WINNEBAGO	PICKUP	OT	111.05	8.44
83	AMERICAN	EAGLE MPV	2C	111.28	7.90
83	BUICK	CENTURY	4S	104.82	6.25
83	CHEVROLET	BLAZER MPV	OT	116.45	8.99
83	CHEVROLET	BLAZER MPV	SW	99.32	7.77
83	CHEVROLET	CAPRICE	4S	107.99	6.01
83	CHEVROLET	CAVALIER	SW	98.47	5.78
83	CHEVROLET	CELEBRITY	4S	103.35	5.69
83	DODGE	600	4S	96.60	5.78
83	FORD	EXP	2C	90.90	6.87
83	FORD	LTD	4S	103.01	5.74
83	FORD	MUSTANG	OT	105.06	7.64
83	FORD	PICKUP	PU	98.66	7.76
83	FORD	TEMPO	4S	95.67	6.72
83	FORD	THUNDERBIRD	2S	106.62	6.30
83	MAZDA	626	4S	96.43	5.77
83	MERCURY	CAPRI	3H	106.91	6.71
83	MITSUBISHI	CORDIA	3H	94.04	5.61
83	MITSUBISHI	MONTERO	OT	123.77	8.59
83	MITSUBISHI	PICKUP	PU	96.05	6.89
83	MITSUBISHI	TREDIA	4S	90.52	5.67
83	NISSAN/DATSUN	PULSAR	5H	86.17	6.18
83	NISSAN/DATSUN	STANZA	4S	90.86	6.41
83	PEUGEOT	505	4S	108.18	8.66
83	PLYMOUTH	RELIANT	SW	88.41	5.66
83	PONTIAC	FIREBIRD	2S	93.83	4.75
83	RENAULT	ALLIANCE	4S	81.36	5.75
83	TOYOTA	CAMRY	4S	93.85	6.42
83	TOYOTA	COROLLA	SW	93.54	6.47
83	TOYOTA	TERCEL	SW	91.45	6.03
83	VOLVO	GLE	4S	106.72	7.18
84	CHEVROLET	CAVALIER	4S	96.34	5.51
84	CHEVROLET	CAVALIER	OT	103.81	6.66
84	CHEVROLET	CELEBRITY	SW	108.58	5.57
84	CHEVROLET	CORVETTE	2C	119.03	6.78
84	CHEVROLET	PICKUP	PU	111.91	6.18
84	DODGE	CARAVAN	VN	111.20	7.14
84	DODGE	DAYTONA	3H	101.51	6.57
84	FORD	BRONCO	UV	103.35	6.85
84	FORD	BRONCO II	UV	112.55	7.81
84	FORD	LTD	SW	109.04	5.54
84	FORD	MUSTANG	CV	110.12	5.70

Table A.1 Front Impacts(Contd.)

Yr	Make	Model	Bd	d0	d1
84	FORD	PICKUP	PU	105.06	5.98
84	FORD	TEMPO	4S	104.95	7.31
84	HONDA	CIVIC	2C	92.71	6.03
84	HONDA	CIVIC	SW	92.86	5.87
84	HONDA	PRELUDE	2C	97.71	6.31
84	ISUZU	IMPULSE	3H	110.14	7.10
84	JEEP	CJ MPV	UV	108.58	8.13
84	MERCEDES	300	4S	114.72	9.90
84	MERCURY	COUGAR	2S	110.59	6.17
84	MITSUBISHI	TREDIA	4S	100.06	6.61
84	NISSAN/DATSUN	200 SX	2S	94.06	6.17
84	NISSAN/DATSUN	300 ZX	2C	112.82	6.50
84	OLDSMOBILE	CUTLASS	2S	105.73	5.61
84	PLYMOUTH	COLT VISTA	SW	106.81	7.68
84	PLYMOUTH	CONQUEST	2C	107.61	6.86
84	PONTIAC	FIERO	2C	106.96	6.36
84	PONTIAC	PARISENE	4S	108.62	5.19
84	RENAULT	ALLIANCE	2S	92.31	6.69
84	RENAULT	ENCORE	5H	94.91	7.51
84	TOYOTA	COROLLA	2C	99.87	6.42
84	TOYOTA	COROLLA	4S	96.17	6.80
84	TOYOTA	TERCEL	5H	91.15	6.09
84	VOLKSWAGEN	RABBIT	5H	100.73	5.78
85	AUDI	5000	4S	106.22	5.86
85	BMW	318	2S	108.45	8.54
85	BUICK	ELECTRA	4S	110.37	5.39
85	BUICK	SOMERSET	2C	106.66	6.12
85	CHEVROLET	ASTRO	VN	111.60	7.88
85	CHEVROLET	BLAZER MPV	SW	115.73	8.13
85	CHEVROLET	SPECTRUM	3H	91.60	5.36
85	CHEVROLET	SPRINT	3H	86.13	6.19
85	DODGE	COLT	5H	97.74	6.26
85	DODGE	LANCER	5H	107.50	6.26
85	FORD	CLUBWAGON MPV	VN	121.75	9.91
85	FORD	MERKUR	3H	110.31	7.35
85	FORD	TEMPO	2S	110.84	6.84
85	FORD	TEMPO	4S	104.53	6.68
85	ISUZU	I-MARK	4S	101.49	6.30
85	ISUZU	TROOPER	OT	112.95	10.13
85	MAZDA	RX	2C	104.36	5.55
85	MITSUBISHI	GALANT	4S	107.44	7.54
85	NISSAN/DATSUN	MAXIMA	SW	112.78	7.70
85	PLYMOUTH	CARAVELLE	4S	101.36	5.48
85	PLYMOUTH	RELIANT	4S	100.82	5.79
85	RENAULT	ALLIANCE	CV	98.66	7.42
85	SUBARU	DL	4S	94.97	5.65
85	TOYOTA	4 X 4	OT	119.87	8.98

Table A.1 Front Impacts(Contd.)

Yr	Make	Model	Bd	d0	d1
85	TOYOTA	CRESSIDA	4S	109.36	7.74
85	TOYOTA	MR2	2S	104.78	6.40
85	VOLKSWAGEN	JETTA	2S	101.58	6.63
85	VOLKSWAGEN	VANAGON	VN	105.69	8.57
85	VOLVO	DL	4S	105.67	5.54
85	VOLVO	DL	SW	107.19	6.62
86	BUICK	CENTURY	2C	103.12	6.13
86	BUICK	CENTURY	4S	101.41	5.74
86	BUICK	LESABRE	2S	107.06	5.32
86	BUICK	SKYLARK	4S	103.14	5.85
86	CHEVROLET	CAVALIER	4S	101.41	6.11
86	CHEVROLET	NOVA	5H	95.54	6.27
86	DODGE	SPORTSMAN VAN	VN	111.34	8.47
86	FORD	AEROSTAR	VN	105.52	7.71
86	FORD	TAURUS	4S	107.38	7.43
86	HONDA	ACCORD	4S	100.60	6.95
86	HYUNDAI	PONY EXCEL	4S	98.90	6.99
86	ISUZU	I-MARK	4S	92.00	6.27
86	ISUZU	PICKUP	PU	108.60	8.97
86	JEEP	COMANCHE	PU	107.78	6.95
86	MAZDA	323	3H	94.06	6.52
86	MAZDA	PICKUP	PU	106.77	9.32
86	MERCURY	SABLE	4S	108.90	8.19
86	MITSUBISHI	CORDIA	3H	103.54	6.13
86	OLDSMOBILE	DELTA 88	4S	107.19	5.18
86	OLDSMOBILE	TORONADO	2C	112.59	5.74
86	PLYMOUTH	COLT VISTA	SW	103.88	7.64
86	SAAB	9000	5H	107.19	7.59
86	SUBARU	GL	4S	94.91	5.46
86	SUBARU	XT	2C	98.20	5.15
86	SUZUKI	SAMURAI	OT	104.78	9.07
86	TOYOTA	CELICA	2C	102.44	6.83
86	VOLKSWAGEN	GOLF	4S	97.40	6.63
86	VOLKSWAGEN	SCIROCCO	3H	109.32	7.08
86	YUGO	GV	3H	92.40	7.16
87	BUICK	LESABRE	2S	106.91	4.77
87	CHEVROLET	CAMARO	3H	107.31	6.46
87	CHEVROLET	LUV PICKUP	PU	101.07	5.42
87	CHEVROLET	SPORTVAN	VN	126.24	8.49
87	CHEVROLET	SUBURBAN	TR	126.28	5.83
87	CHRYSLER	LE BARON	2C	109.76	4.93
87	CHRYSLER	LE BARON	2S	107.65	5.17
87	DODGE	DAKOTA	PU	106.49	6.42
87	DODGE	SHADOW	3H	102.65	5.99
87	FORD	AEROSTAR	VN	103.03	8.12
87	FORD	ESCORT	3H	98.90	6.73
87	FORD	ESCORT	5H	100.46	6.47

Table A.1 Front Impacts(Contd.)

Yr	Make	Model	Bd	d0	d1
87	FORD	MUSTANG	3H	105.82	6.55
87	FORD	RANGER	PU	103.14	6.15
87	HONDA	ACCORD	3H	98.54	6.85
87	HONDA	ACURA-INTEGRA	3H	98.30	6.42
87	HYUNDAI	PONY EXCEL	3H	96.34	5.67
87	HYUNDAI	PONY EXCEL	4S	96.83	6.47
87	HYUNDAI	PONY EXCEL	5H	94.80	6.66
87	ISUZU	I-MARK	4S	95.69	6.47
87	ISUZU	PICKUP	PU	105.65	8.52
87	JEEP	COMANCHE	PU	107.50	8.09
87	JEEP	WRANGLER MPV	UV	116.07	11.53
87	MAZDA	626	4S	102.36	5.98
87	MERCURY	LYNX	5H	98.37	6.93
87	MERCURY	TOPAZ	4S	106.83	7.25
87	MITSUBISHI	STARION	3H	112.27	6.79
87	NISSAN/DATSUN	200 SX	3H	99.21	6.52
87	NISSAN/DATSUN	PICKUP	PU	100.75	6.78
87	NISSAN/DATSUN	SENTRA	5H	99.34	6.15
87	OLDSMOBILE	CALAIS	2C	105.20	6.05
87	OLDSMOBILE	CALAIS	4S	105.82	6.36
87	PEUGEOT	505	4S	104.78	6.31
87	PLYMOUTH	SUNDANCE	5H	104.34	5.50
87	PLYMOUTH	VOYAGER VAN	VN	109.53	7.30
87	PONTIAC	GRAND AM	2S	101.34	6.42
87	PONTIAC	SUNBIRD	4S	102.63	6.76
87	RENAULT	ALLIANCE	2S	91.95	6.49
87	SAAB	9000	5H	109.95	6.75
87	SUBARU	GL	4S	91.76	5.98
87	SUBARU	JUSTY	3H	85.88	6.24
87	SUBARU	XT	2C	101.24	5.97
87	TOYOTA	CAMRY	4S	106.49	8.25
87	TOYOTA	CELICA	2S	91.51	6.32
87	TOYOTA	PICKUP	PU	100.73	7.81
87	VOLKSWAGEN	FOX	2S	95.10	6.79
87	VOLKSWAGEN	GOLF	5H	99.17	6.21
87	YUGO	GV	3H	92.48	7.84
88	AMERICAN	EAGLE PREMIER	4S	108.41	6.91
88	BUICK	REGAL	2S	110.10	6.57
88	CHEVROLET	ASTRO	VN	108.77	6.63
88	CHEVROLET	BERETTA	2S	111.85	6.48
88	CHEVROLET	CORSICA	4S	111.41	6.47
88	CHEVROLET	PICKUP	PU	107.44	5.14
88	CHEVROLET	SPORTVAN	VN	111.32	8.44
88	CHRYSLER	NEW YORKER	4S	111.03	5.63
88	DAIHATSU	CHARADE	3H	90.01	5.79
88	DODGE	COLT	SW	94.63	4.91
88	DODGE	PICKUP	PU	102.44	4.95

Table A.1 Front Impacts(Contd.)

Yr	Make	Model	Bd	d0	d1
88	FORD	FESTIVA	3H	88.64	7.51
88	FORD	PICKUP	PU	106.62	5.68
88	FORD	TAURUS	4S	110.50	7.79
88	FORD	TEMPO	4S	103.94	7.31
88	HONDA	ACURA-LEGEND	4S	110.10	7.98
88	HONDA	CIVIC	3H	91.36	6.98
88	ISUZU	SPACEBAR	PU	113.75	7.77
88	MAZDA	929	4S	114.11	7.10
88	MAZDA	RX	2S	112.08	6.76
88	MITSUBISHI	MONTERO	OT	110.16	10.74
88	NISSAN/DATSUN	MAXIMA	4S	111.05	7.66
88	NISSAN/DATSUN	PICKUP	PU	100.37	9.69
88	NISSAN/DATSUN	PULSAR	3H	102.61	6.03
88	NISSAN/DATSUN	SENTRA	SW	97.97	6.45
88	NISSAN/DATSUN	VAN	VN	117.19	9.31
88	OLDSMOBILE	DELTA 88	4S	110.50	5.83
88	PEUGEOT	505	4S	106.28	6.48
88	PONTIAC	LEMANS	2C	99.00	8.07
88	RENAULT	MEDALLION	4S	101.89	7.01
88	SAAB	900	3H	111.18	7.59
88	TOYOTA	COROLLA	3H	98.90	6.33
88	TOYOTA	CRESSIDA	4S	111.43	7.58
88	TOYOTA	TERCEL	3H	93.81	6.91
88	VOLKSWAGEN	FOX	2S	97.14	7.32
88	VOLKSWAGEN	VANAGON	VN	111.15	10.57
88	VOLVO	GLE	4S	107.27	6.77
88	YUGO	GV	3H	90.90	8.14

Table A.2 Rear Impacts

Yr	Make	Model	Bd	d0	d1
78	BMW	320 I	2S	112.29	5.61
78	BUICK	OPEL	2C	109.36	3.49
78	BUICK	REGAL	2C	107.80	4.05
78	CHEVROLET	CAPRICE	4S	100.41	4.69
78	CHEVROLET	CHEVETTE	5H	97.44	5.44
78	CHEVROLET	MALIBU	4S	107.67	5.11
78	CHEVROLET	MONZA	3H	102.76	6.21
78	CHEVROLET	SPORTVAN	VN	105.48	11.32
78	DODGE	SPORTSMAN VAN	VN	100.56	6.55
78	FIAT	SPIDER	2C	110.29	5.67
78	FORD	COURIER	PU	103.39	7.17
78	FORD	FAIRMONT	2S	95.44	5.81
78	FORD	GRANADA	4S	99.66	5.69
78	FORD	RANCHERO	PU	104.40	6.05
78	FORD	VAN	VN	101.51	7.05
78	GMC	PICKUP	PU	110.29	7.74
78	HONDA	ACCORD	3H	94.93	4.10
78	JEEP	TOWNSIDE MPV	OT	99.70	15.40
78	MAZDA	COSMO	2S	102.15	5.70
78	NISSAN/DATSUN	510	4S	98.52	4.38
78	NISSAN/DATSUN	PICKUP	PU	113.58	7.75
78	OLDSMOBILE	DELTA 88	2C	101.07	4.28
78	PLYMOUTH	HORIZON	5H	107.99	4.14
78	PLYMOUTH	SAPPORO	2C	98.62	5.34
78	PONTIAC	LEMANS	2S	108.37	5.71
78	SUBARU	DL	4S	96.24	3.44
78	TOYOTA	COROLLA	2S	95.48	5.49
78	TOYOTA	PICKUP	PU	100.27	4.22
78	TRIUMPH	SPITFIRE	2C	103.69	4.63
79	BUICK	ELECTRA	4S	99.91	4.32
79	CADILLAC	SEVILLE	4S	110.94	6.47
79	CHECKER	TAXICAB	4S	103.14	7.41
79	CHEVROLET	CAMARO	2C	97.76	6.96
79	CHEVROLET	CHEVETTE	5H	96.74	4.45
79	CHRYSLER	CORDOBA	2S	99.19	5.47
79	CHRYSLER	NEWPORT	4S	98.09	5.45
79	DODGE	ASPEN	2C	98.39	4.80
79	DODGE	OMNI	5H	96.45	4.51
79	FIAT	STRADA	3H	100.50	6.36
79	FORD	FIESTA	3H	90.96	4.54
79	FORD	MUSTANG	2S	102.67	6.97
79	FORD	PINTO	3H	93.39	4.32
79	HONDA	CIVIC	3H	90.94	4.13
79	MAZDA	GLC	3H	96.05	5.97
79	MAZDA	RX	3H	101.36	7.06
79	MERCURY	MONARCH	4S	96.55	5.05
79	MERCURY	ZEPHYR	4S	95.52	4.35

Table A.2 Rear Impacts(Contd.)

Yr	Make	Model	Bd	d0	d1
79	MG	MIDGET	OT	102.55	7.02
79	NISSAN/DATSUN	210	2S	92.08	9.23
79	NISSAN/DATSUN	280	3H	104.00	5.64
79	NISSAN/DATSUN	310	3H	94.40	6.26
79	PLYMOUTH	ARROW PICKUP	3H	98.75	9.84
79	PONTIAC	CATALINA	4S	98.58	5.25
79	PONTIAC	GRAND PRIX	2C	98.52	4.59
79	PONTIAC	SUNBIRD	2C	98.60	5.36
79	SUBARU	DL	2C	96.47	3.55
79	TOYOTA	CELICA	2C	102.17	7.42
79	TOYOTA	CELICA	3H	96.95	6.16
79	TOYOTA	COROLLA	2S	94.21	4.88
79	TRIUMPH	SPITFIRE	OT	98.09	10.63
79	VOLKSWAGEN	DASHER	3H	100.44	7.40
79	VOLKSWAGEN	RABBIT	3H	92.67	4.25
79	VOLKSWAGEN	SCIROCCO	2C	95.71	5.88
79	VOLVO	244	2S	98.73	5.22
80	AMERICAN	CONCORD	2S	101.03	6.21
80	AMERICAN	EAGLE MPV	2S	104.97	9.15
80	BUICK	RIVIERA	2C	104.72	4.82
80	CHEVROLET	CITATION	5H	96.64	4.42
80	DODGE	MIRADA	2C	98.58	5.14
80	FIAT	STRADA	5H	96.95	5.38
80	HONDA	CIVIC	3H	90.69	4.96
80	HONDA	PRELUDE	2C	93.03	5.20
80	MAZDA	626	4S	99.21	6.70
80	MERCURY	COUGAR	2C	96.30	4.44
80	NISSAN/DATSUN	200 SX	2C	100.27	4.85
80	NISSAN/DATSUN	310	2S	92.40	5.40
80	OLDSMOBILE	CUTLASS	4S	100.06	5.05
80	RENAULT	LE CAR	3H	92.82	6.32
80	SUBARU	GL	4S	93.98	3.60
80	TOYOTA	COROLLA	2S	95.52	5.62
80	TOYOTA	COROLLA	4S	95.63	5.64
80	VOLKSWAGEN	RABBIT	OT	101.89	6.15
81	CHRYSLER	IMPERIAL	2C	108.10	5.74
81	DODGE	ARIES	2S	92.52	3.55
81	NISSAN/DATSUN	810	4S	104.72	7.09
81	PLYMOUTH	SAPPORO	2C	102.99	8.22
81	RENAULT	18	4S	95.37	4.18
81	TOYOTA	CRESSIDA	4S	104.30	5.42
81	VOLKSWAGEN	JETTA	4S	100.79	3.76
82	DODGE	400	2C	97.84	4.61
82	DODGE	COLT PICKUP	PU	102.63	5.02
82	DODGE	PICKUP	PU	102.15	6.62
82	DODGE	RAMPAGE	OT	98.73	4.45
82	GMC	S15 PICKUP	PU	98.94	6.15

Table A.2 Rear Impacts(Contd.)

Yr	Make	Model	Bd	d0	d1
82	HONDA	ACCORD	4S	94.04	3.10
82	ISUZU	PICKUP	PU	99.74	4.68
82	MAZDA	PICKUP	PU	101.43	6.57
82	NISSAN/DATSUN	PICKUP	PU	105.31	6.18
82	NISSAN/DATSUN	STANZA	5H	94.17	5.46
82	TOYOTA	LAND CRUISER	MP	109.21	22.17
82	TOYOTA	PICKUP	PU	99.72	5.88
83	AMERICAN	EAGLE MPV	3H	105.37	9.81
83	CHEVROLET	BLAZER MPV	OT	108.52	8.65
83	CHEVROLET	LUV PICKUP	PU	104.17	8.02
83	DODGE	600	4S	98.54	3.82
83	FORD	PICKUP	PU	99.78	8.10
83	FORD	THUNDERBIRD	2C	105.12	4.97
83	MAZDA	PICKUP	PU	103.28	6.43
83	MITSUBISHI	MONTERO	OT	105.56	12.58
83	MITSUBISHI	PICKUP	PU	99.11	6.42
83	NISSAN/DATSUN	200 SX	3H	100.82	5.96
83	OLDSMOBILE	CUTLASS	2C	103.77	4.92
83	PLYMOUTH	PICKUP	PU	100.33	4.66
83	TOYOTA	TERCEL	SW	99.25	5.41
83	VOLVO	GLE	4S	102.69	5.59
84	BUICK	ELECTRA	4S	102.38	4.58
84	CHEVROLET	EL CAMINO	PU	102.12	6.13
84	CHRYSLER	OTHER	4S	101.60	4.28
84	DODGE	DAYTONA	3H	103.03	4.71
84	DODGE	MINIRAM VAN	VN	101.64	6.86
84	DODGE	PICKUP	PU	96.91	8.47
84	FORD	BRONCO II	UV	107.38	13.67
84	HONDA	CIVIC	2C	92.65	4.72
84	ISUZU	PICKUP	PU	105.92	4.76
84	JEEP	CHEROKEE MPV	SW	101.70	6.41
84	MAZDA	PICKUP	PU	103.47	6.95
84	MERCURY	CAPRI	3H	103.60	6.51
84	NISSAN/DATSUN	200 SX	2C	100.39	6.37
84	NISSAN/DATSUN	280	2C	104.87	8.98
84	NISSAN/DATSUN	PICKUP	PU	106.30	5.88
84	PLYMOUTH	COLT VISTA	SW	106.24	5.70
84	PONTIAC	BONNEVILLE	4S	105.27	6.43
84	PONTIAC	FIERO	2C	100.46	5.71
84	PONTIAC	PARISENE	SW	101.22	5.63
84	RENAULT	ENCORE	5H	96.55	6.22
84	RENAULT	OTHER	SW	104.63	6.69
84	SUBARU	GLF	SW	94.95	5.43
84	TOYOTA	COROLLA	4S	100.37	6.02
84	TOYOTA	PICKUP	PU	102.88	6.91
84	TOYOTA	SUPRA	VN	105.16	9.13
85	AMERICAN	ALLIANCE	OT	100.58	6.66

Table A.2 Rear Impacts(Contd.)

Yr	Make	Model	Bd	d0	d1
85	CHEVROLET	ASTRO	VN	104.57	9.74
85	CHEVROLET	BLAZER MPV	OT	104.76	9.59
85	CHEVROLET	SPECTRUM	4S	96.01	4.03
85	DODGE	ARIES	4S	100.69	4.13
85	DODGE	COLT	4S	98.01	3.86
85	DODGE	OTHER	5H	104.57	7.32
85	SUBARU	DL	4S	96.57	3.30
85	SUBARU	GL	SW	93.75	4.02
85	VOLKSWAGEN	GOLF	3H	97.90	5.81
86	FORD	TAURUS	4S	104.19	5.97
86	MAZDA	323	3H	96.09	5.39
86	TOYOTA	CELICA	2C	101.83	6.02
86	YUGO	GV	3H	94.21	5.21
87	NISSAN/DATSUN	MAXIMA	4S	104.72	4.64
87	NISSAN/DATSUN	SENTRA	2S	94.93	4.17

Table A.3 Side Impacts

Yr	Make	Model	B		d0	d1
80	AMERICAN	CONCORD		SW	63.30	5.97
80	CHEVROLET	CITATION		5H	63.30	4.85
80	FORD	LTD		4S	63.30	6.58
81	CHEVROLET	CITATION		5H	63.30	6.21
81	DODGE	OMNI		3H	63.30	5.80
81	FORD	GRANADA		2S	63.30	5.51
81	FORD	GRANADA		4S	63.30	5.00
81	HONDA	CIVIC		4S	63.30	6.05
81	PLYMOUTH	HORIZON		5H	63.30	6.38
81	VOLKSWAGEN	RABBIT		2S	63.30	5.60
81	VOLKSWAGEN	RABBIT		3H	63.30	6.30
82	CHEVROLET	CITATION		3H	63.30	5.39
82	CHEVROLET	CITATION		5H	63.30	6.46
82	DODGE	400		2C	63.30	4.43
82	HONDA	CIVIC		4S	63.30	6.15
82	NISSAN/DATSUN	SENTRA		2S	63.30	4.93
82	VOLKSWAGEN	RABBIT		2S	63.30	6.93
82	VOLKSWAGEN	RABBIT		3H	63.30	5.71
83	FORD	ESCORT		3H	63.30	4.52
83	MAZDA	626		4S	63.30	4.57
83	MITSUBISHI	TREDIA		4S	63.30	3.82
83	NISSAN/DATSUN	SENTRA		2S	63.30	5.36
84	CHEVROLET	CELEBRITY		4S	63.30	6.86
84	FORD	RANGER		PU	63.30	4.28
85	CHEVROLET	CELEBRITY		4S	63.30	6.01
85	CHEVROLET	SPECTRUM		3H	63.30	6.58
87	CHEVROLET	CAVALIER		4S	63.30	6.63
87	NISSAN/DATSUN	SENTRA		2S	63.30	5.11
88	CHEVROLET	CAPRICE		4S	63.30	7.64
88	CHEVROLET	S10 PICKUP		PU	63.30	7.11
88	CHEVROLET	SPRINT		3H	63.30	5.80
88	DODGE	CARAVAN		VN	63.30	5.64
88	FORD	PICKUP		PU	63.30	4.82
88	FORD	TAURUS		4S	63.30	7.37
88	HYUNDAI	EXCEL GLS		4S	63.30	5.38
88	NISSAN/DATSUN	PICKUP		PU	63.30	7.00
88	PONTIAC	BONNEVILLE		4S	63.30	5.88
88	TOYOTA	TERCEL		5H	63.30	8.23
88	VOLKSWAGEN	GOLF		3H	63.30	6.61

REFERENCES

1."CRASH3 Technical Manual", 1986, Accident Investigation Division, NCSA, NHTSA.

2.Prasad, Aloke K., and Monk, Michael W., "CRASH3 Damage Algorithm Reformulation, Volume I", March 1990, VRTC report No. VRTC-87-0053.

3.Prasad, Aloke K., and Monk, Michael W., "CRASH3 Damage Algorithm Reformulation, Volume II", March 1990, VRTC report No. VRTC-87-0053.

4.Report on the Crash Avoidance Inertial Parameter Measurement Program at VRTC, to be published.

APPENDIX B

SAS© Regression Analysis

This Appendix contains the results of regression analysis carried out to examine the important factors affecting the MAIS and FATAL (the number of fatalities in an accident) values. The analysis is carried out for two sets of data. Sections B.1 through B.10 contain the results of analyzing all the front impact cases, including those where the ΔV have been calculated using conservation of momentum. Sections B.11 through B.18 contain similar analysis carried out on cases where ΔV has been calculated using the more reliable CRASH3 damage algorithm.

Each set contains results of procedures RSQUARE (for obtaining the best combinations of upto four independent variables), regression analysis for some selected independent variables, the regression results for upto four independent variables having the highest R^2 values, and the result of the STEPWISE procedure.

B.1 SAS© Input files:

The SAS© input file for regression analysis is shown below. This file contains all the front impact cases including those with ΔV calculated using the conservation of momentum method.

```
Data truck;
input
year psu case natwgt full engmnt impang mais intrusn fatal deltav method gfactor ofactor;
cards;
    81  28  12  797   0   50   10   2    0   0  62.0 0 0.3  0.7
    81  53 214  206   0   10    0   1    0   0   .   0 0.5  0.5
    82   5 143  101   0   60   -5   6   12   1  89.0 0 0.6  0.2
    82  54 116  107   1   10  -30   5   12   0   .   0   1  0.2
    82  53 227 48.2   1  100   10   7   12   1  83.7 0 0.2  0.4
    82  53 103 80.4   0   50    0   7   12   1   .   0 0.4  0.3
    83  80  25  108   0   20    0   3    6   0  18.2 1 0.5  0.4
    83  53 102 60.3   0   40  -20   6   12   1  35.6 1 0.7  0.7
    83  30  12  132   0   50  -10   5   12   0  14.8 1 0.6  0.1
    83  53 200  145   0   50   25   5   12   1  42.8 1   0  0.5
    83   8 289  126   0   90   60   3    6   0  43.2 1   0    0
    83  29 168  159   0   50    0   2    0   0  28.0 1 0.2  0.5
    84  54  96 80.9   1   90    5   3    6   0  34.7 1 0.7  0.1
    84  82  19 58.3   1   40  -30   2   12   0  28.0 1 0.4  0.2
    84  12  35 76.5   1  100    0   6   12   1  99.8 0 0.4  0.5
    84  76  29 55.7   0   20  -70   2    0   0  50.7 0   0  0.2
    85  11 133  104   1  100    5   6   12   2  50.0 1 0.4  0.2
    85  79  78 19.9   0   90    0   6   12   1  88.7 0 0.7    0
    85  38 227 38.1   1  100   30   6   12   1  49.3 1 0.5  0.5
    85  12  56 92.2   1  100   10   7   12   1 104.0 0   0  0.2
    85  12  21   91   1   95   45   6   12   1  99.8 0 0.9  0.2
    85  11 275   45   0  100   30   5   12   1  68.6 1   0  0.1
    85  29 105  103   0   30   -5   2    0   0   9.9 1 0.4  0.6
    85  59 110  105   1  100    0   2    0   0  17.4 1 0.5  0.7
    85  38 330 76.3   1  100   10   1    0   0  30.6 0 0.5  0.2
    86  58 176 53.6   0   50    0   6   12   1  32.2 1 0.6  0.7
    86  61  46  117   0   40   60   3    0   0  22.3 1 0.1  0.1
    86  33  38 73.7   1   90   30   3   12   0  58.0 1 0.3  0.1
    86  13  52 92.1   0   70  -20   3    1   0  21.0 1 0.8  0.7
    86  59 189 66.6   0   20    0   1    0   0   6.6 1 0.4  0.5
    87  38  65    .   1  100   25   5   12   2  34.2 1 0.3  0.4
```

```
data aloke.truck;
set truck;
deltavsq=deltav*deltav;
deltavcu=deltav*deltav*deltav;
deltavrt=sqrt(deltav);
engf1=1-(engmnt/100);
engf2=4*(engmnt/100)*(1-(engmnt/100));

proc print;

data cr3delv;
set aloke.truck;
if method=1;

proc reg data=aloke.truck;
model mais= full engmnt impang intrusn deltav gfactor ofactor deltavsq engf1 engf2 deltavcu deltavrt/selection=-
rsquare cp;
model mais= intrusn;
model mais= deltav;
model mais= intrusn deltav;
model mais= intrusn deltav ofactor;
model mais= full engmnt impang intrusn deltav gfactor ofactor fatal deltavsq engf1 engf2 deltavcu
deltavrt/selection=maxr;
model mais= full engmnt impang intrusn deltav gfactor ofactor fatal deltavsq engf1 engf2 deltavcu
deltavrt/selection=stepwise;

model fatal= full engmnt impang intrusn deltav gfactor ofactor deltavsq engf1 engf2 deltavcu
deltavrt/selection=rsquare cp;
model fatal= intrusn;
model fatal= deltav;
model fatal= intrusn deltav;
model fatal= intrusn deltav ofactor;
model fatal= full engmnt impang intrusn deltav gfactor ofactor deltavsq engf1 engf2 deltavcu
deltavrt/selection=maxr;
model fatal= full engmnt impang intrusn deltav gfactor ofactor deltavsq engf1 engf2 deltavcu
deltavrt/selection=stepwise;

proc reg data=cr3delv;
model mais= full engmnt impang intrusn deltav gfactor ofactor deltavsq engf1 engf2 deltavcu
deltavrt/selection=rsquare cp;
model mais= intrusn;
model mais= deltav;
model mais= intrusn deltav;
model mais= intrusn deltav ofactor;
model mais= full engmnt impang intrusn deltav gfactor ofactor fatal deltavsq engf1 engf2 deltavcu
deltavrt/selection=maxr;
model mais= full engmnt impang intrusn deltav gfactor ofactor fatal deltavsq engf1 engf2 deltavcu
deltavrt/selection=stepwise;

model fatal= full engmnt impang intrusn deltav gfactor ofactor deltavsq engf1 engf2 deltavcu
deltavrt/selection=rsquare cp;
model fatal= intrusn;
model fatal= deltav;
model fatal= intrusn deltav;
model fatal= intrusn deltav ofactor;
model fatal= full engmnt impang intrusn deltav gfactor ofactor deltavsq engf1 engf2 deltavcu
deltavrt/selection=maxr;
model fatal= full engmnt impang intrusn deltav gfactor ofactor deltavsq engf1 engf2 deltavcu
deltavrt/selection=stepwise;

run;
```

B.2 SAS© Data set:

The SAS© input file for regression analysis is shown in Table B.1. This data set contains all the front impact cases including those with ΔV calculated using the conservation of momentum method. It also has the calculated values of ΔV^2, ΔV^3, $\sqrt{\Delta V}$, and the two engagement factors (equations (4.1) and (4.2)).

Table B.1 SAS© Dataset for all front impacts

OBS	YEAR	PSU	CASE	NATWGT	FULL	ENGMNT	IMPANG	MAIS	INTRUSN	FATAL	DELTAV	METHOD	GFACTOR	OFACTOR	DELTAVSQ	DELTAVCU	DELTAVRT	ENGF1	ENGF2
1	81	28	12	797.0	0	50	10	2	0	0	62.0	0	0.3	0.7	3844.00	238328.00	7.8740	0.50	1.00
2	81	53	214	206.0	0	10	0	1	0	0	.	0	0.5	0.5	.	.	.	0.90	0.36
3	82	5	143	101.0	0	60	-5	6	12	1	89.0	0	0.6	0.2	7921.00	704969.00	9.4340	0.40	0.96
4	82	54	116	107.0	1	10	-30	5	12	0	.	0	1.0	0.2	.	.	.	0.90	0.36
5	82	53	227	48.2	1	100	10	7	12	1	83.7	0	0.2	0.4	7005.69	586376.25	9.1488	0.00	0.00
6	82	53	103	80.4	0	50	0	7	12	1	.	0	0.4	0.3	.	.	.	0.50	1.00
7	83	80	25	108.0	0	20	0	3	6	0	18.2	1	0.5	0.4	331.24	6028.57	4.2661	0.80	0.64
8	83	53	102	60.3	0	40	-20	6	12	1	35.6	1	0.7	0.7	1267.36	45118.02	5.9666	0.60	0.96
9	83	30	12	132.0	0	50	-10	5	12	0	14.8	1	0.6	0.1	219.04	3241.79	3.8471	0.50	1.00
10	83	53	200	145.0	0	50	25	5	12	1	42.8	1	0.0	0.5	1831.84	78402.75	6.5422	0.50	1.00
11	83	8	289	126.0	0	90	60	3	6	0	43.2	1	0.0	0.0	1866.24	80621.57	6.5727	0.10	0.36
12	83	29	168	159.0	0	50	0	2	0	0	28.0	1	0.2	0.5	784.00	21952.00	5.2915	0.50	1.00
13	84	54	96	80.9	1	90	5	3	6	0	34.7	1	0.7	0.1	1204.09	41781.92	5.8907	0.10	0.36
14	84	82	19	58.3	1	40	-30	2	12	0	28.0	1	0.4	0.2	784.00	21952.00	5.2915	0.60	0.96
15	84	12	35	76.5	1	100	0	6	12	1	99.8	0	0.4	0.5	9960.04	994011.99	9.9900	0.00	0.00
16	84	76	29	55.7	0	20	-70	2	0	0	50.7	0	0.0	0.2	2570.49	130323.84	7.1204	0.80	0.64
17	85	11	133	104.0	1	100	5	6	12	2	50.0	1	0.4	0.2	2500.00	125000.00	7.0711	0.00	0.00
18	85	79	78	19.9	0	90	0	6	12	1	88.7	0	0.7	0.0	7867.69	697864.10	9.4181	0.10	0.36
19	85	38	227	38.1	1	100	30	6	12	1	49.3	1	0.5	0.5	2430.49	119823.16	7.0214	0.00	0.00
20	85	12	56	92.2	1	100	10	7	12	1	104.0	0	0.0	0.2	10816.00	1124864.00	10.1980	0.00	0.00
21	85	12	21	91.0	1	95	45	6	12	1	99.8	0	0.9	0.2	9960.04	994011.99	9.9900	0.05	0.19
22	85	11	275	45.0	0	100	30	5	12	1	68.6	1	0.0	0.1	4705.96	322828.86	8.2825	0.00	0.00
23	85	29	105	103.0	0	30	-5	2	0	0	9.9	1	0.4	0.6	98.01	970.30	3.1464	0.70	0.84
24	85	59	110	105.0	1	100	0	2	0	0	17.4	1	0.5	0.7	302.76	5268.02	4.1713	0.00	0.00
25	85	38	330	76.3	1	100	10	1	0	0	30.6	0	0.5	0.2	936.36	28652.62	5.5317	0.00	0.00
26	86	58	176	53.6	0	50	0	6	12	1	32.2	1	0.6	0.7	1036.84	33386.25	5.6745	0.50	1.00
27	86	61	46	117.0	0	40	60	3	0	0	22.3	1	0.1	0.1	497.29	11089.57	4.7223	0.60	0.96
28	86	33	38	73.7	1	90	30	3	12	0	58.0	1	0.3	0.1	3364.00	195112.00	7.6158	0.10	0.36
29	86	13	52	92.1	0	70	-20	3	1	0	21.0	1	0.8	0.7	441.00	9261.00	4.5826	0.30	0.84
30	86	59	189	66.6	0	20	0	1	0	0	6.6	1	0.4	0.5	43.56	287.50	2.5690	0.80	0.64
31	87	38	65	.	1	100	25	5	12	2	34.2	1	0.3	0.4	1169.64	40001.69	5.8481	0.00	0.00

B.3 SAS© RSQUARE Procedure output, for MAIS, all cases:

The SAS© output for the RSQUARE procedure, giving the value of $\hat{R}$ for the selected best combinations of independent variables are given below. The results for upto four independent variables are presented.

N = 28 Regression Models for Dependent Variable: MAIS

Number in Model	R-square	C(p)	Variables in Model
1	0.69823537	10.21178	INTRUSN
1	0.43680203	39.85110	DELTAV
1	0.43664867	39.86849	DELTAVRT
1	0.41158441	42.71008	DELTAVSQ
1	0.38297047	45.95411	DELTAVCU
1	0.19361308	67.42201	ENGMNT
1	0.19361308	67.42201	ENGF1
1	0.08319932	79.93988	ENGF2
1	0.03786816	85.07919	FULL
1	0.03254332	85.68288	IMPANG
1	0.01391518	87.79479	GFACTOR
1	0.00776714	88.49181	OFACTOR
2	0.76935178	4.14914	INTRUSN DELTAVCU
2	0.76768956	4.33759	INTRUSN DELTAVSQ
2	0.75960265	5.25442	INTRUSN DELTAV
2	0.75118316	6.20896	INTRUSN DELTAVRT
2	0.71774671	9.99973	INTRUSN OFACTOR
2	0.71123148	10.73838	ENGMNT INTRUSN
2	0.71123148	10.73838	INTRUSN ENGF1
2	0.70539115	11.40051	INTRUSN ENGF2
2	0.70330385	11.63715	FULL INTRUSN
2	0.70032434	11.97495	IMPANG INTRUSN
2	0.69889047	12.13751	INTRUSN GFACTOR
2	0.47076380	38.00077	GFACTOR DELTAVRT
3	0.80203836	2.44338	INTRUSN OFACTOR DELTAVSQ
3	0.80108934	2.55098	INTRUSN OFACTOR DELTAVCU
3	0.79640710	3.08181	INTRUSN DELTAV OFACTOR
3	0.78809930	4.02369	INTRUSN OFACTOR DELTAVRT
3	0.78452767	4.42861	FULL INTRUSN DELTAVCU
3	0.78172156	4.74675	FULL INTRUSN DELTAVSQ
3	0.77291003	5.74573	FULL INTRUSN DELTAV
3	0.77030520	6.04105	INTRUSN GFACTOR DELTAVCU
3	0.77021561	6.05121	ENGMNT INTRUSN DELTAVCU
3	0.77021561	6.05121	INTRUSN ENGF1 DELTAVCU
3	0.77019213	6.05387	IMPANG INTRUSN DELTAVCU
3	0.76965619	6.11463	INTRUSN GFACTOR DELTAVSQ
4	0.81461620	3.01740	FULL INTRUSN OFACTOR DELTAVCU
4	0.81452480	3.02777	FULL INTRUSN OFACTOR DELTAVSQ
4	0.80837312	3.72520	FULL INTRUSN DELTAV OFACTOR
4	0.80701763	3.87887	IMPANG INTRUSN OFACTOR DELTAVSQ
4	0.80629476	3.96083	IMPANG INTRUSN OFACTOR DELTAVCU
4	0.80422285	4.19572	ENGMNT INTRUSN OFACTOR DELTAVSQ
4	0.80422285	4.19572	INTRUSN OFACTOR DELTAVSQ ENGF1
4	0.80418773	4.19971	ENGMNT INTRUSN OFACTOR DELTAVCU
4	0.80418773	4.19971	INTRUSN OFACTOR ENGF1 DELTAVCU
4	0.80380267	4.24336	FULL ENGMNT INTRUSN DELTAVCU
4	0.80380267	4.24336	FULL INTRUSN ENGF1 DELTAVCU
4	0.80324035	4.30711	INTRUSN OFACTOR DELTAVCU DELTAVRT

NOTE: Models of not full rank are not included.

B.4 SAS© Regression MAIS vs. selected independent variables, all cases:

The SAS© output for the REG procedure, for selected independent variables are given below.

B.4.1 MAIS vs. INTRUSN:

Model: MODEL2
Dependent Variable: MAIS

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	71.12026	71.12026	60.160	0.0001
Error	26	30.73688	1.18219		
C Total	27	101.85714			

Root MSE	1.08728	R-square	0.6982
Dep Mean	4.07143	Adj R-sq	0.6866
C.V.	26.70524		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	1.856139	0.35184582	5.275	0.0001
INTRUSN	1	0.293972	0.03790118	7.756	0.0001

B.4.2 MAIS vs. DELTAV:

Model: MODEL3
Dependent Variable: MAIS

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	44.49141	44.49141	20.165	0.0001
Error	26	57.36574	2.20637		
C Total	27	101.85714			

Root MSE	1.48539	R-square	0.4368
Dep Mean	4.07143	Adj R-sq	0.4151
C.V.	36.48319		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	2.003773	0.53926868	3.716	0.0010
DELTAV	1	0.043757	0.00974418	4.491	0.0001

B.4.3 MAIS vs. INTRUSN and DELTAV:

Model: MODEL4
Dependent Variable: MAIS

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	77.37096	38.68548	39.497	0.0001
Error	25	24.48619	0.97945		
C Total	27	101.85714			

Root MSE	0.98967	R-square	0.7596
Dep Mean	4.07143	Adj R-sq	0.7404
C.V.	24.30769		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	1.357396	0.37622035	3.608	0.0013
INTRUSN	1	0.237801	0.04104322	5.794	0.0001
DELTAV	1	0.019512	0.00772392	2.526	0.0182

B.4.4 MAIS vs. INTRUSN, DELTAV, and OVERRIDE FACTOR:

Model: MODEL5
Dependent Variable: MAIS

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	3	81.11975	27.03992	31.294	0.0001
Error	24	20.73739	0.86406		
C Total	27	101.85714			

Root MSE	0.92955	R-square	0.7964
Dep Mean	4.07143	Adj R-sq	0.7710
C.V.	22.83098		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	0.559344	0.52121264	1.073	0.2939
INTRUSN	1	0.248160	0.03886930	6.384	0.0001
DELTAV	1	0.022526	0.00739758	3.045	0.0056
OFACTOR	1	1.667202	0.80041209	2.083	0.0481

B.5 SAS© MAXR Regression MAIS vs. best independent variables, all cases:

The SAS© output for MAXR procedure, for upto 4 best independent variables are given below.

```
Maximum R-square Improvement for Dependent Variable MAIS
Step 1   Variable INTRUSN Entered   R-square = 0.69823537   C(p) = 19.69454679

                DF         Sum of Squares      Mean Square          F   Prob>F
 Regression      1            71.12025964      71.12025964      60.16   0.0001
 Error          26            30.73688322       1.18218782
 Total          27           101.85714286

                Parameter        Standard          Type II
 Variable        Estimate           Error   Sum of Squares          F   Prob>F
 INTERCEP      1.85613852      0.35184582      32.90049764      27.83   0.0001
 INTRUSN       0.29397214      0.03790118      71.12025964      60.16   0.0001

Bounds on condition number:            1,            1
The above model is the best  1-variable model found.
----------------------------------------------------------------------------------------------------

Step 2   Variable FATAL Entered     R-square = 0.79161642   C(p) =  8.17327174

                DF         Sum of Squares      Mean Square          F   Prob>F
  Regression     2            80.63178642      40.31589321      47.49   0.0001
  Error         25            21.22535643       0.84901426
  Total         27           101.85714286

                Parameter        Standard          Type II
  Variable       Estimate           Error   Sum of Squares          F   Prob>F
  INTERCEP      1.95786517      0.29971680      36.22916874      42.67   0.0001
  INTRUSN       0.18711642      0.04528638      14.49451327      17.07   0.0004
  FATAL         1.31321405      0.39234479       9.51152678      11.20   0.0026

Bounds on condition number:      1.98793,     7.951721
The above model is the best  2-variable model found.

Step 3   Variable DELTAVCU Entered  R-square = 0.84230930   C(p) =  2.83310568

                DF         Sum of Squares      Mean Square          F   Prob>F
  Regression     3            85.79521856      28.59840619      42.73   0.0001
  Error         24            16.06192430       0.66924685
  Total         27           101.85714286

                Parameter        Standard          Type II
  Variable       Estimate           Error   Sum of Squares          F   Prob>F
  INTERCEP      1.91609271      0.26652578      34.58923229      51.68   0.0001
  INTRUSN       0.15744749      0.04160175       9.58593829      14.32   0.0009
  FATAL         1.17289883      0.35198401       7.43124478      11.10   0.0028
  DELTAVCU      0.00000143      0.00000052       5.16343214       7.72   0.0105

Bounds on condition number:     2.128227,     16.34414
----------------------------------------------------------------------------------------------------
The above model is the best  3-variable model found.

Step 4   Variable FULL Entered      R-square = 0.86403477   C(p) =  1.68732776

                DF         Sum of Squares      Mean Square          F   Prob>F
  Regression     4            88.00811275      22.00202819      36.54   0.0001
  Error         23            13.84903011       0.60213174
  Total         27           101.85714286
                Parameter        Standard          Type II
  Variable       Estimate           Error   Sum of Squares          F   Prob>F
  INTERCEP      2.04693877      0.26186017      36.79275869      61.10   0.0001
  FULL         -0.61136661      0.31890928       2.21289419       3.68   0.0677
  INTRUSN       0.16563958      0.03969135      10.48643738      17.42   0.0004
  FATAL         1.22913088      0.33515461       8.09836564      13.45   0.0013
  DELTAVCU      0.00000160      0.00000050       6.23066364      10.35   0.0038

Bounds on condition number:     2.153185,     26.74799
The above model is the best  4-variable model found.
```

B.6 SAS© STEPWISE Regression MAIS vs. best independent variables, all cases:

Summary of Stepwise Procedure for Dependent Variable MAIS

Step	Variable Entered	Variable Removed	Number In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	INTRUSN		1	0.6982	0.6982	19.6945	60.1599	0.0001
2	FATAL		2	0.0934	0.7916	8.1733	11.2030	0.0026
3	DELTAVCU		3	0.0507	0.8423	2.8331	7.7153	0.0105
4	FULL		4	0.0217	0.8640	1.6873	3.6751	0.0677

B.7 SAS© RSQUARE Procedure output, for FATAL , all cases:

The SAS© output for the RSQUARE procedure, giving the value of R for the selected best combinations of independent variables are given below. The results for upto four independent variables are presented.

N = 28 Regression Models for Dependent Variable: FATAL

Number in Model	R-square	C(p)	Variables in Model
1	0.49696425	1.41625	INTRUSN
1	0.27308891	12.72772	DELTAVRT
1	0.25142176	13.82246	DELTAV
1	0.22245396	15.28608	ENGF1
1	0.22245396	15.28608	ENGMNT
1	0.20287490	16.27533	DELTAVSQ
1	0.17839319	17.51229	ENGF2
1	0.17015106	17.92873	DELTAVCU
1	0.08794788	22.08210	FULL
1	0.03110681	24.95404	IMPANG
1	0.00056946	26.49696	GFACTOR
1	0.00000077	26.52569	OFACTOR
2	0.56255985	0.10198	INTRUSN ENGF2
2	0.53933555	1.27541	INTRUSN ENGF1
2	0.53933555	1.27541	ENGMNT INTRUSN
2	0.53534020	1.47728	INTRUSN OFACTOR
2	0.52003500	2.25058	INTRUSN DELTAVRT
2	0.51718016	2.39483	INTRUSN DELTAV
2	0.51086772	2.71377	INTRUSN DELTAVSQ
2	0.50732546	2.89274	INTRUSN DELTAVCU
2	0.50326350	3.09798	FULL INTRUSN
2	0.50094100	3.21532	IMPANG INTRUSN
2	0.49993783	3.26601	INTRUSN GFACTOR
2	0.32234205	12.23916	ENGF2 DELTAVRT
3	0.62635379	-1.12125	INTRUSN OFACTOR ENGF2
3	0.59538468	0.44349	INTRUSN OFACTOR ENGF1
3	0.59538468	0.44349	ENGMNT INTRUSN OFACTOR
3	0.58259560	1.08966	FULL INTRUSN ENGF2
3	0.57426505	1.51057	INTRUSN OFACTOR DELTAVRT
3	0.56921704	1.76563	INTRUSN DELTAV OFACTOR
3	0.56680883	1.88730	INTRUSN ENGF2 DELTAVRT
3	0.56540336	1.95831	INTRUSN DELTAV ENGF2
3	0.56352765	2.05309	INTRUSN DELTAVSQ ENGF2
3	0.56311250	2.07406	INTRUSN GFACTOR ENGF2
3	0.56289911	2.08484	INTRUSN ENGF2 DELTAVCU
3	0.56267754	2.09604	ENGMNT INTRUSN ENGF2
4	0.65549877	-0.59382	FULL INTRUSN OFACTOR ENGF2
4	0.63726186	0.32761	INTRUSN OFACTOR ENGF2 DELTAVRT
4	0.63412140	0.48628	INTRUSN DELTAV OFACTOR ENGF2
4	0.63315972	0.53487	INTRUSN GFACTOR OFACTOR ENGF2
4	0.62963261	0.71308	INTRUSN OFACTOR DELTAVSQ ENGF2
4	0.62814844	0.78807	IMPANG INTRUSN OFACTOR ENGF2

```
      4     0.62780411      0.80547   INTRUSN OFACTOR ENGF2 DELTAVCU
      4     0.62637636      0.87761   ENGMNT INTRUSN OFACTOR ENGF2
      4     0.62637636      0.87761   INTRUSN OFACTOR ENGF1 ENGF2
      4     0.60901674      1.75472   INTRUSN GFACTOR OFACTOR ENGF1
      4     0.60901674      1.75472   ENGMNT INTRUSN GFACTOR OFACTOR
      4     0.60639236      1.88731   INTRUSN OFACTOR ENGF1 DELTAVRT
-----------------------------------------------------------------------
```

B.8 SAS© Regression FATAL vs. selected independent variables, all cases:

The SAS© output for the REG procedure, for selected independent variables are given below.

B.8.1 FATAL vs. INTRUSN:

```
Model: MODEL9
Dependent Variable: FATAL

                        Analysis of Variance
                           Sum of          Mean
    Source          DF     Squares        Square      F Value       Prob>F
    Model            1     5.44886       5.44886       25.686       0.0001
    Error           26     5.51543       0.21213
    C Total         27    10.96429
        Root MSE       0.46058     R-square       0.4970
        Dep Mean       0.53571     Adj R-sq       0.4776
        C.V.          85.97451
                      Parameter Estimates
                   Parameter       Standard    T for H0:
  Variable  DF     Estimate          Error   Parameter=0    Prob > |T|
  INTERCEP   1    -0.077464     0.14904317        -0.520        0.6076
  INTRUSN    1     0.081370     0.01605508         5.068        0.0001
```

B.8.2 FATAL vs. DELTAV:

```
Model: MODEL10
Dependent Variable: FATAL

                        Analysis of Variance
                           Sum of          Mean
    Source          DF     Squares        Square      F Value       Prob>F
    Model            1     2.75666       2.75666         8.733       0.0066
    Error           26     8.20763       0.31568
    C Total         27    10.96429
        Root MSE       0.56185     R-square       0.2514
        Dep Mean       0.53571     Adj R-sq       0.2226
        C.V.         104.87908
                      Parameter Estimates
                   Parameter       Standard    T for H0:
  Variable  DF     Estimate          Error   Parameter=0    Prob > |T|
  INTERCEP   1     0.021041     0.20398005         0.103        0.9186
  DELTAV     1     0.010892     0.00368577         2.955        0.0066
```

B.8.3 FATAL vs. INTRUSN and DELTAV:

```
Model: MODEL11
Dependent Variable: FATAL
                        Analysis of Variance
                           Sum of          Mean
    Source          DF     Squares        Square      F Value       Prob>F

    Model            2     5.67051       2.83526       13.390       0.0001
    Error           25     5.29377       0.21175
    C Total         27    10.96429
```

```
       Root MSE        0.46016      R-square        0.5172
       Dep Mean        0.53571      Adj R-sq        0.4786
       C.V.           85.89730

                    Parameter Estimates
                  Parameter       Standard    T for H0:
 Variable  DF      Estimate          Error   Parameter=0    Prob > |T|
 INTERCEP   1     -0.171382     0.17493006        -0.980        0.3366
 INTRUSN    1      0.070792     0.01908374         3.710        0.0010
 DELTAV     1      0.003674     0.00359137         1.023        0.3161
```

B.8.4 FATAL vs. INTRUSN, DELTAV, and OVERRIDE FACTOR:

```
Model: MODEL12
Dependent Variable: FATAL

                        Analysis of Variance
                           Sum of          Mean
   Source           DF     Squares        Square      F Value       Prob>F
   Model             3     6.24106       2.08035       10.571       0.0001
   Error            24     4.72323       0.19680
   C Total          27    10.96429
       Root MSE       0.44362      R-square        0.5692
       Dep Mean       0.53571      Adj R-sq        0.5154
       C.V.          82.80958

                    Parameter Estimates
                  Parameter       Standard    T for H0:
 Variable  DF      Estimate          Error   Parameter=0    Prob > |T|
 INTERCEP   1     -0.482719     0.24874669        -1.941        0.0641
 INTRUSN    1      0.074833     0.01855022         4.034        0.0005
 DELTAV     1      0.004850     0.00353047         1.374        0.1822
 OFACTOR    1      0.650411     0.38199354         1.703        0.1015
```

B.9 SAS© MAXR Regression FATAL vs. best independent variables, all cases:

The SAS© output for MAXR procedure, for upto 4 best independent variables are given below.

```
Maximum R-square Improvement for Dependent Variable FATAL

Step 1   Variable INTRUSN Entered   R-square = 0.49696425   C(p) =  1.41625017

                 DF         Sum of Squares      Mean Square          F   Prob>F
  Regression      1             5.44885804       5.44885804      25.69   0.0001
  Error          26             5.51542768       0.21213183
  Total          27            10.96428571
                 Parameter        Standard          Type II
  Variable        Estimate           Error   Sum of Squares          F   Prob>F
  INTERCEP      -0.07746387      0.14904317       0.05730336       0.27   0.6076
  INTRUSN        0.08136961      0.01605508       5.44885804      25.69   0.0001

Bounds on condition number:            1,            1
The above model is the best  1-variable model found.
----------------------------------------------------------------------------------------------------

Step 2   Variable ENGF2 Entered     R-square = 0.56255985   C(p) =  0.10198418

                 DF         Sum of Squares      Mean Square          F   Prob>F
  Regression      2             6.16806698       3.08403349      16.08   0.0001
  Error          25             4.79621874       0.19184875
  Total          27            10.96428571
                 Parameter        Standard          Type II
  Variable        Estimate           Error   Sum of Squares          F   Prob>F
  INTERCEP       0.17985488      0.19429914       0.16438481       0.86   0.3635
  INTRUSN        0.07383116      0.01575684       4.21211309      21.96   0.0001
  ENGF2         -0.39902717      0.20608881       0.71920894       3.75   0.0642

Bounds on condition number:     1.065026,     4.260106
The above model is the best  2-variable model found.
----------------------------------------------------------------------------------------------------
```

Step 3 Variable OFACTOR Entered R-square = 0.62635379 C(p) = -1.12125106

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	3	6.86752188	2.28917396	13.41	0.0001
Error	24	4.09676383	0.17069849		
Total	27	10.96428571			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	-0.07983777	0.22371557	0.02173973	0.13	0.7243
INTRUSN	0.08053656	0.01522760	4.77477861	27.97	0.0001
OFACTOR	0.72097194	0.35616673	0.69945490	4.10	0.0542
ENGF2	-0.47982837	0.19845292	0.99789893	5.85	0.0236

Bounds on condition number: 1.121892, 10.04925
The above model is the best 3-variable model found.

Step 4 Variable FULL Entered R-square = 0.65549877 C(p) = -0.59382255

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	4	7.18707577	1.79676894	10.94	0.0001
Error	23	3.77720994	0.16422652		
Total	27	10.96428571			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	0.13952059	0.26996321	0.04386425	0.27	0.6102
FULL	-0.32166655	0.23059798	0.31955389	1.95	0.1764
INTRUSN	0.08525980	0.01531513	5.08968219	30.99	0.0001
OFACTOR	0.77554758	0.35153351	0.79933111	4.87	0.0376
ENGF2	-0.75047666	0.27483733	1.22452096	7.46	0.0119

Bounds on condition number: 2.220296, 26.97729
The above model is the best 4-variable model found.

B.10 SAS© STEPWISE Regression FATAL vs. best independent variables, all cases:

Summary of Stepwise Procedure for Dependent Variable FATAL

Step	Variable Entered	Variable Removed	Number In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	INTRUSN		1	0.4970	0.4970	1.4163	25.6862	0.0001
2	ENGF2		2	0.0656	0.5626	0.1020	3.7488	0.0642
3	OFACTOR		3	0.0638	0.6264	-1.1213	4.0976	0.0542

B.11 SAS© RSQUARE Procedure output, for MAIS, cases using CRASH3:

The SAS© output for the RSQUARE procedure, giving the value of R^2 for the selected best combinations of independent variables are given below. The results for four independent variables are presented.

N = 19 Regression Models for Dependent Variable: MAIS

Number in Model	R-square	C(p)	Variables in Model
1	0.59651000	4.43975	INTRUSN
1	0.33579373	17.00080	DELTAVRT
1	0.30008590	18.72117	DELTAV
1	0.21722919	22.71312	DELTAVSQ
1	0.15000739	25.95180	DELTAVCU
1	0.11548102	27.61525	ENGMNT
1	0.11548102	27.61525	ENGF1
1	0.03267833	31.60460	ENGF2
1	0.01255837	32.57396	IMPANG
1	0.00782543	32.80199	GFACTOR
1	0.00322841	33.02347	FULL
1	0.00129844	33.11646	OFACTOR
2	0.65500637	3.62145	INTRUSN OFACTOR
2	0.63171161	4.74377	FULL INTRUSN
2	0.60770383	5.90044	INTRUSN GFACTOR
2	0.60738455	5.91582	ENGMNT INTRUSN
2	0.60738455	5.91582	INTRUSN ENGF1
2	0.60661326	5.95298	IMPANG INTRUSN
2	0.60367835	6.09439	INTRUSN DELTAVRT
2	0.59990682	6.27609	INTRUSN DELTAV
2	0.59798870	6.36851	INTRUSN ENGF2
2	0.59680993	6.42530	INTRUSN DELTAVSQ
2	0.59655929	6.43738	INTRUSN DELTAVCU
2	0.43973194	13.99316	GFACTOR DELTAVRT
3	0.72388526	2.30294	IMPANG INTRUSN OFACTOR
3	0.70175348	3.36922	FULL ENGMNT INTRUSN
3	0.70175348	3.36922	FULL INTRUSN ENGF1
3	0.68095652	4.37120	INTRUSN OFACTOR DELTAVRT
3	0.68063893	4.38650	FULL INTRUSN OFACTOR
3	0.68023168	4.40612	ENGMNT INTRUSN OFACTOR
3	0.68023168	4.40612	INTRUSN OFACTOR ENGF1
3	0.67512874	4.65198	INTRUSN DELTAV OFACTOR
3	0.66979199	4.90910	FULL INTRUSN ENGF2
3	0.66625654	5.07943	INTRUSN OFACTOR DELTAVSQ
3	0.66226519	5.27173	INTRUSN OFACTOR ENGF2
3	0.66152986	5.30716	INTRUSN OFACTOR DELTAVCU
4	0.77569557	1.80677	FULL ENGMNT INTRUSN OFACTOR
4	0.77569557	1.80677	FULL INTRUSN OFACTOR ENGF1
4	0.76645220	2.25210	IMPANG INTRUSN GFACTOR OFACTOR
4	0.75307616	2.89655	FULL ENGMNT INTRUSN GFACTOR
4	0.75307616	2.89655	FULL INTRUSN GFACTOR ENGF1
4	0.74814253	3.13424	FULL ENGMNT INTRUSN DELTAVCU
4	0.74814253	3.13424	FULL INTRUSN ENGF1 DELTAVCU
4	0.74234067	3.41377	FULL IMPANG INTRUSN OFACTOR
4	0.73878743	3.58496	FULL ENGMNT INTRUSN DELTAVSQ
4	0.73878743	3.58496	FULL INTRUSN DELTAVSQ ENGF1
4	0.73841887	3.60272	FULL IMPANG INTRUSN GFACTOR
4	0.73347746	3.84079	FULL INTRUSN OFACTOR ENGF2

B.12 SAS© Regression MAIS vs. selected independent variables, cases using CRASH3:

The SAS© output for the REG procedure, for selected independent variables are given below.

B.12.1 MAIS vs. INTRUSN:

```
Model: MODEL24
Dependent Variable: MAIS
                        Analysis of Variance
                           Sum of          Mean
    Source          DF      Squares        Square      F Value       Prob>F
    Model            1     29.63713      29.63713       25.132       0.0001
    Error           17     20.04708       1.17924
    C Total         18     49.68421
        Root MSE       1.08593     R-square       0.5965
        Dep Mean       3.73684     Adj R-sq       0.5728
        C.V.          29.06005
                        Parameter Estimates
                    Parameter      Standard    T for H0:
  Variable  DF      Estimate         Error   Parameter=0    Prob > |T|
  INTERCEP   1      2.010287    0.42506100         4.729        0.0002
  INTRUSN    1      0.236004    0.04707630         5.013        0.0001
```

B.12.2 MAIS vs. DELTAV:

```
Model: MODEL34
Dependent Variable: MAIS
                        Analysis of Variance
                           Sum of          Mean
    Source          DF      Squares        Square      F Value       Prob>F
    Model            1     14.90953      14.90953         7.289       0.0152
    Error           17     34.77468       2.04557
    C Total         18     49.68421
        Root MSE       1.43023     R-square       0.3001
        Dep Mean       3.73684     Adj R-sq       0.2589
        C.V.          38.27387
                        Parameter Estimates
                    Parameter      Standard    T for H0:
  Variable  DF      Estimate         Error   Parameter=0    Prob > |T|
  INTERCEP   1      1.966997    0.73308673         2.683        0.0157
  DELTAV     1      0.054696    0.02025956         2.700        0.0152
```

B.12.3 MAIS vs. INTRUSN and DELTAV:

```
Model: MODEL44
Dependent Variable: MAIS
                        Analysis of Variance
                           Sum of          Mean
    Source          DF      Squares        Square      F Value       Prob>F

    Model            2     29.80590      14.90295        11.995       0.0007
    Error           16     19.87831       1.24239
    C Total         18     49.68421
        Root MSE       1.11463     R-square       0.5999
        Dep Mean       3.73684     Adj R-sq       0.5499
        C.V.          29.82806
                        Parameter Estimates
                    Parameter      Standard    T for H0:
  Variable  DF      Estimate         Error   Parameter=0    Prob > |T|
  INTERCEP   1      1.873981    0.57194935         3.276        0.0047
  INTRUSN    1      0.220687    0.06373332         3.463        0.0032
  DELTAV     1      0.007675    0.02082515         0.369        0.7173
```

B.12.4 MAIS vs. INTRUSN, DELTAV, and OVERRIDE FACTOR:

Model: MODEL54
Dependent Variable: MAIS

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	3	33.54324	11.18108	10.391	0.0006
Error	15	16.14097	1.07606		
C Total	18	49.68421			

Root MSE	1.03734	R-square	0.6751
Dep Mean	3.73684	Adj R-sq	0.6102
C.V.	27.75968		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	0.744278	0.80671298	0.923	0.3708
INTRUSN	1	0.220112	0.05931463	3.711	0.0021
DELTAV	1	0.019687	0.02042469	0.964	0.3504
OFACTOR	1	1.994293	1.07010582	1.864	0.0821

B.13 SAS© MAXR Regression MAIS vs. best independent variables, cases Using CRASH3:

The SAS© output for MAXR procedure, for upto 4 best independent variables are given below.

```
Maximum R-square Improvement for Dependent Variable MAIS
Step 1   Variable FATAL Entered     R-square = 0.61722100   C(p) = 37.40308959

                 DF         Sum of Squares      Mean Square          F   Prob>F
  Regression      1            30.66613824      30.66613824      27.41   0.0001
  Error          17            19.01807229       1.11871013
  Total          18            49.68421053

                 Parameter        Standard          Type II
  Variable        Estimate           Error   Sum of Squares          F   Prob>F
  INTERCEP      2.84939759      0.29598958      103.67423540      92.67   0.0001
  FATAL         1.87349398      0.35783395       30.66613824      27.41   0.0001

Bounds on condition number:           1,           1
The above model is the best  1-variable model found.
----------------------------------------------------------------------------------------------------

Step 2   Variable INTRUSN Entered   R-square = 0.75017819   C(p) = 21.20102607

                 DF         Sum of Squares      Mean Square          F   Prob>F
  Regression      2            37.27201134      18.63600567      24.02   0.0001
  Error          16            12.41219919       0.77576245
  Total          18            49.68421053

                 Parameter        Standard          Type II
  Variable        Estimate           Error   Sum of Squares          F   Prob>F
  INTERCEP      2.13628782      0.34708977       29.38763558      37.88   0.0001
  INTRUSN       0.14176793      0.04858221        6.60587310       8.52   0.0101
  FATAL         1.18942102      0.37913929        7.63488291       9.84   0.0064

Bounds on condition number:     1.618912,     6.475649
The above model is the best  2-variable model found.
----------------------------------------------------------------------------------------------------

Step 3   Variable FULL Entered      R-square = 0.80410324   C(p) = 15.81859639

                 DF         Sum of Squares      Mean Square          F   Prob>F
  Regression      3            39.95123469      13.31707823      20.52   0.0001
  Error          15             9.73297584       0.64886506
  Total          18            49.68421053

                 Parameter        Standard          Type II
  Variable        Estimate           Error   Sum of Squares          F   Prob>F
  INTERCEP      2.28032609      0.32525297       31.89376234      49.15   0.0001
  FULL         -0.82240184      0.40472200        2.67922335       4.13   0.0603
  INTRUSN       0.15843875      0.04518248        7.97878887      12.30   0.0032
  FATAL         1.26751460      0.34886940        8.56514212      13.20   0.0025

Bounds on condition number:     1.674108,     13.28688
The above model is the best  3-variable model found.
----------------------------------------------------------------------------------------------------

Step 4   Variable GFACTOR Entered   R-square = 0.84421181   C(p) = 12.32766608

                 DF         Sum of Squares      Mean Square          F   Prob>F
  Regression      4            41.94399714      10.48599929      18.97   0.0001
  Error          14             7.74021338       0.55287238
  Total          18            49.68421053

                 Parameter        Standard          Type II
  Variable        Estimate           Error   Sum of Squares          F   Prob>F
  INTERCEP      1.75874545      0.40695904       10.32593693      18.68   0.0007
  FULL         -0.96822394      0.38140131        3.56297013       6.44   0.0236
  INTRUSN       0.15741636      0.04171013        7.87483571      14.24   0.0021
  GFACTOR       1.39679373      0.73572745        1.99276246       3.60   0.0784
  FATAL         1.34936185      0.32490421        9.53610617      17.25   0.0010
Bounds on condition number:     1.674387,     22.24443
The above model is the best  4-variable model found.
```

B.14 SAS© STEPWISE Regression MAIS vs. best independent variables, cases using CRASH3:

Summary of Stepwise Procedure for Dependent Variable MAIS

Step	Variable Entered	Removed	Number In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	FATAL		1	0.6172	0.6172	37.4031	27.4121	0.0001
2	INTRUSN		2	0.1330	0.7502	21.2010	8.5153	0.0101
3	FULL		3	0.0539	0.8041	15.8186	4.1291	0.0603
4	GFACTOR		4	0.0401	0.8442	12.3277	3.6044	0.0784
5	IMPANG		5	0.0698	0.9140	4.7784	10.5398	0.0064

B.15 SAS© RSQUARE Procedure output, for FATAL , cases using CRASH3:

The SAS© output for the RSQUARE procedure, giving the value of R^2 for the selected best combinations of independent variables are given below. The results for upto four independent variables are presented.

N = 19 Regression Models for Dependent Variable: FATAL

Number in Model	R-square	C(p)	Variables in Model
1	0.38230131	0.37640	INTRUSN
1	0.26989227	3.17460	DELTAVRT
1	0.25648873	3.50825	DELTAV
1	0.19533259	5.03062	DELTAVSQ
1	0.18030193	5.40477	ENGF2
1	0.17634585	5.50325	ENGMNT
1	0.17634585	5.50325	ENGF1
1	0.13528460	6.52539	DELTAVCU
1	0.07343660	8.06498	FULL
1	0.01424031	9.53855	IMPANG
1	0.01162804	9.60358	OFACTOR
1	0.00989505	9.64672	GFACTOR
2	0.48191055	-0.10318	INTRUSN ENGF2
2	0.45811003	0.48929	INTRUSN OFACTOR
2	0.43948082	0.95303	INTRUSN ENGF1
2	0.43948082	0.95303	ENGMNT INTRUSN
2	0.40262850	1.87039	INTRUSN DELTAVRT
2	0.40085609	1.91451	INTRUSN DELTAV
2	0.39442119	2.07470	IMPANG INTRUSN
2	0.39205597	2.13357	INTRUSN DELTAVSQ
2	0.38979727	2.18980	FULL INTRUSN
2	0.38963473	2.19385	INTRUSN GFACTOR
2	0.38608126	2.28230	INTRUSN DELTAVCU
2	0.37790130	2.48593	OFACTOR DELTAVRT
3	0.59776757	-0.98721	INTRUSN OFACTOR ENGF2
3	0.55051498	0.18905	INTRUSN OFACTOR ENGF1
3	0.55051498	0.18905	ENGMNT INTRUSN OFACTOR
3	0.54437758	0.34183	IMPANG INTRUSN OFACTOR
3	0.51540975	1.06292	INTRUSN GFACTOR OFACTOR
3	0.51338934	1.11322	INTRUSN DELTAV OFACTOR
3	0.51175585	1.15388	INTRUSN OFACTOR DELTAVRT
3	0.50051814	1.43362	FULL INTRUSN ENGF2
3	0.50006427	1.44492	INTRUSN OFACTOR DELTAVSQ
3	0.49649112	1.53387	INTRUSN ENGF2 DELTAVCU
3	0.48923790	1.71442	INTRUSN DELTAVSQ ENGF2
3	0.48563272	1.80416	INTRUSN OFACTOR DELTAVCU
4	0.64638685	-0.19749	INTRUSN GFACTOR OFACTOR ENGF2
4	0.63086232	0.18896	IMPANG INTRUSN OFACTOR ENGF2
4	0.61597202	0.55962	FULL INTRUSN OFACTOR ENGF2
4	0.60519044	0.82801	INTRUSN GFACTOR OFACTOR ENGF1
4	0.60519044	0.82801	ENGMNT INTRUSN GFACTOR OFACTOR

```
      4      0.60401624       0.85724   INTRUSN OFACTOR ENGF2 DELTAVRT
      4      0.60160921       0.91716   INTRUSN DELTAV OFACTOR ENGF2
      4      0.59825805       1.00058   INTRUSN OFACTOR ENGF2 DELTAVCU
      4      0.59795419       1.00814   INTRUSN OFACTOR DELTAVSQ ENGF2
      4      0.59777398       1.01263   INTRUSN OFACTOR ENGF1 ENGF2
      4      0.59777398       1.01263   ENGMNT INTRUSN OFACTOR ENGF2
      4      0.59065407       1.18986   IMPANG INTRUSN OFACTOR ENGF1
 ----------------------------------------------------------------
```

B.16 SAS© Regression FATAL vs. selected independent variables, cases using CRASH3:

The SAS© output for the REG procedure, for selected independent variables are given below.

B.16.1 FATAL vs. INTRUSN:

```
Model: MODEL94
Dependent Variable: FATAL

                        Analysis of Variance
                           Sum of          Mean
    Source          DF     Squares        Square      F Value       Prob>F
    Model            1     3.34011       3.34011       10.522       0.0048
    Error           17     5.39674       0.31746
    C Total         18     8.73684
        Root MSE       0.56343     R-square       0.3823
        Dep Mean       0.47368     Adj R-sq       0.3460
        C.V.         118.94665
                        Parameter Estimates
                    Parameter      Standard    T for H0:
  Variable  DF      Estimate         Error   Parameter=0    Prob > |T|
  INTERCEP   1     -0.105935    0.22054197        -0.480        0.6371
  INTRUSN    1      0.079228    0.02442544         3.244        0.0048
```

B.16.2 FATAL vs. DELTAV:

```
Model: MODEL10
Dependent Variable: FATAL

                        Analysis of Variance
                           Sum of          Mean
    Source          DF     Squares        Square      F Value       Prob>F
    Model            1     2.24090       2.24090         5.864       0.0269
    Error           17     6.49594       0.38211
    C Total         18     8.73684
        Root MSE       0.61815     R-square       0.2565
        Dep Mean       0.47368     Adj R-sq       0.2128
        C.V.         130.49914
                        Parameter Estimates
                    Parameter      Standard    T for H0:
  Variable  DF      Estimate         Error   Parameter=0    Prob > |T|
  INTERCEP   1     -0.212459    0.31684351        -0.671        0.5115
  DELTAV     1      0.021205    0.00875628         2.422        0.0269
```

B.16.3 FATAL vs. INTRUSN and DELTAV:

```
Model: MODEL11
Dependent Variable: FATAL

                        Analysis of Variance
                           Sum of          Mean
    Source          DF     Squares        Square      F Value       Prob>F

    Model            2     3.50222       1.75111         5.352       0.0166
    Error           16     5.23463       0.32716
    C Total         18     8.73684
```

```
       Root MSE       0.57198     R-square       0.4009
       Dep Mean       0.47368     Adj R-sq       0.3260
       C.V.         120.75189

                  Parameter Estimates
                Parameter      Standard    T for H0:
  Variable  DF    Estimate         Error   Parameter=0    Prob > |T|
  INTERCEP   1   -0.239525    0.29350170        -0.816        0.4264
  INTRUSN    1    0.064217    0.03270541         1.963        0.0672
  DELTAV     1    0.007523    0.01068664         0.704        0.4916
```

B.16.4 FATAL vs. INTRUSN, DELTAV, and OVERRIDE FACTOR:

```
Model: MODEL12
Dependent Variable: FATAL

                        Analysis of Variance
                           Sum of          Mean
    Source           DF    Squares        Square      F Value       Prob>F
    Model             3    4.48540       1.49513        5.275       0.0110
    Error            15    4.25144       0.28343
    C Total          18    8.73684
        Root MSE       0.53238     R-square       0.5134
        Dep Mean       0.47368     Adj R-sq       0.4161
        C.V.         112.39151

                  Parameter Estimates
                Parameter      Standard    T for H0:
  Variable  DF    Estimate         Error   Parameter=0    Prob > |T|
  INTERCEP   1   -0.818955    0.41402089        -1.978        0.0666
  INTRUSN    1    0.063922    0.03044143         2.100        0.0531
  DELTAV     1    0.013683    0.01048235         1.305        0.2114
  OFACTOR    1    1.022881    0.54919925         1.862        0.0822
```

B.17 SAS© MAXR Regression FATAL vs. best independent variables, cases using CRASH3:

The SAS© output for MAXR procedure, for upto 4 best independent variables are given below.

```
Maximum R-square Improvement for Dependent Variable FATAL

Step 1   Variable INTRUSN Entered   R-square = 0.38230131   C(p) =  0.37639660

                 DF         Sum of Squares      Mean Square          F   Prob>F
  Regression      1             3.34010620       3.34010620      10.52   0.0048
  Error          17             5.39673591       0.31745505
  Total          18             8.73684211

                Parameter        Standard          Type II
  Variable       Estimate           Error   Sum of Squares          F   Prob>F
  INTERCEP     -0.10593472      0.22054197       0.07324473       0.23   0.6371
  INTRUSN       0.07922849      0.02442544       3.34010620      10.52   0.0048

Bounds on condition number:            1,           1
The above model is the best  1-variable model found.
----------------------------------------------------------------------------------------------------

Step 2   Variable ENGF2 Entered     R-square = 0.48191055   C(p) = -0.10317990

                 DF         Sum of Squares      Mean Square          F   Prob>F
  Regression      2             4.21037639       2.10518819       7.44   0.0052
  Error          16             4.52646572       0.28290411
  Total          18             8.73684211

                Parameter        Standard          Type II
  Variable       Estimate           Error   Sum of Squares          F   Prob>F
  INTERCEP      0.25928450      0.29445774       0.21935443       0.78   0.3916
  INTRUSN       0.07160990      0.02346354       2.63510693       9.31   0.0076
  ENGF2        -0.53847816      0.30701576       0.87027019       3.08   0.0986

Bounds on condition number:     1.035489,     4.141956
```

```
The above model is the best  2-variable model found.
-----------------------------------------------------------------------------------------------------------

Step 3   Variable OFACTOR Entered   R-square = 0.59776757   C(p) = -0.98721299
                 DF         Sum of Squares      Mean Square          F   Prob>F
  Regression      3             5.22260086       1.74086695       7.43   0.0028
  Error          15             3.51424125       0.23428275
  Total          18             8.73684211

                 Parameter        Standard          Type II
  Variable        Estimate           Error   Sum of Squares          F   Prob>F

  INTERCEP      -0.12638738      0.32593059       0.03522877       0.15   0.7036
  INTRUSN        0.08180612      0.02190849       3.26653153      13.94   0.0020
  OFACTOR        1.00254056      0.48231825       1.01222447       4.32   0.0552
  ENGF2         -0.64905937      0.28441018       1.22016586       5.21   0.0375

Bounds on condition number:     1.108968,     9.816424
The above model is the best  3-variable model found.
-----------------------------------------------------------------------------------------------------------

Step 4   Variable GFACTOR Entered   R-square = 0.64638685   C(p) = -0.19749462

                 DF         Sum of Squares      Mean Square          F   Prob>F
  Regression      4             5.64737986       1.41184496       6.40   0.0038
  Error          14             3.08946225       0.22067587
  Total          18             8.73684211

                 Parameter        Standard          Type II
  Variable        Estimate           Error   Sum of Squares          F   Prob>F
  INTERCEP      -0.00808088      0.32761599       0.00013426       0.00   0.9807
  INTRUSN        0.08518576      0.02140185       3.49611984      15.84   0.0014
  GFACTOR       -0.70837505      0.51057456       0.42477900       1.92   0.1870
  OFACTOR        1.32783971      0.52353987       1.41953674       6.43   0.0237
  ENGF2         -0.62939286      0.27639127       1.14432621       5.19   0.0390

Bounds on condition number:     1.387192,     19.36332
The above model is the best  4-variable model found.
-----------------------------------------------------------------------------------------------------------
```

B.18 SAS© STEPWISE Regression FATAL vs. best independent variables, cases using CRASH3:

```
        Summary of Stepwise Procedure for Dependent Variable FATAL
        Variable        Number   Partial    Model
  Step  Entered Removed     In      R**2      R**2       C(p)          F   Prob>F
     1  INTRUSN              1    0.3823    0.3823     0.3764    10.5215   0.0048
     2  ENGF2                2    0.0996    0.4819    -0.1032     3.0762   0.0986
     3  OFACTOR              3    0.1159    0.5978    -0.9872     4.3205   0.0552
```

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